The Shipyard State of the Art Report

May 2000

Contents
The Shipyard State of the Art Report

Contents (Continued)
The Shipyard State of the Art Report

Contents (Continued)
The Shipyard State of the Art Report

Figures
The Shipyard State of the Art Report

Figures

Section 1

Executive Summary

The Shipyard State of the Art (SOA) Report has been developed in support of the U.S. Navy MARITECH Advanced Shipbuilding Enterprise (ASE) program. Three shipyard production-related Major Initiative Panels were chartered by the Executive Control Board of the National Shipbuilding Research Program (NSRP) to produce this SOA annual report. The panels included Shipyard Production Process Technologies (SP-16); Welding Technologies (SP-7); and Surface Preparation and Coating Technologies (SP-3). A team of representatives from U.S. shipyards and the Navy Manufacturing Technology Program Centers of Excellence worked together to produce the report, which focuses on shipyard production processes and related technologies. Government and industry groups may use the report as a basis for comparing current practices with SOA practices. The SOA report also strives to improve the U.S. industry in a manner that is consistent with the mission and vision of the MARITECH ASE program, as described below.

The U.S. Navy has worked with industry, the Defense Advanced Research Projects Agency, the Maritime Administration, and the U.S. Coast Guard to develop the MARITECH ASE program. This program is strategically structured to place industry in such a position so as to control its own destiny. The shipbuilding industry strongly endorses this new program. The Executive Control Board of the NSRP took the lead in forming the collaborative organizational structure required to develop and administer a landmark, industry-wide strategic, research and development investment plan on a cost-share basis with government, funded by the U.S. Navy's MARITECH ASE program. Participation in MARITECH ASE is open and accessible to the entire maritime industry.

MISSION: The mission of MARITECH ASE and the NSRP is to manage and focus national shipbuilding research and development funding on technologies which reduce the cost of warships to the U.S. Navy and foster U.S. international shipbuilding competitiveness.

VISION: Industry has developed a consensus vision for U.S. shipbuilding as a common frame of reference for collaborative, coordinated research and development. By 2006 and through the collaborative development of product and process improvements, the U.S. shipbuilding industry will become a robust, self-sufficient industry that:

- Is recognized as able to build ships as efficiently and cost effectively as world competitive shipyards, and has captured a significantly increased share of commercial markets.
- Has significantly reduced the cost of ships to the U.S. Navy; adjusted to the substantial reduction in military construction; and preserved the infrastructure support which the U.S. Navy shipbuilding needs for the foreseeable future.
- Continues to be characterized by customer satisfaction, safety, quality, environmental compliance, and increasingly lean cost and cycle time.

The SOA report is purposely structured to highlight production processes. It is divided into three chapters, one for each of the participating panels. Each Discrete Process write-up provides an Introduction; a State of the Industry; a State of the Art; a State of Related Industry; an Enabling Technologies; and a Manufacturing Strategies section. The MARITECH ASE Strategic Investment Plan Sub-initiatives; Product Control; Industrial Engineering; Outfit Fabrication/Installation/Test; Structural Fabrication/ Subassembly/Assembly and Erection; Production Control; and Surface Preparation and Coatings were used as a guide for SOA process selection. The development team recognized the need to prioritize the area of report development due to the broad scope of shipyard production processes.

ACKNOWLEDGMENT

We would like to thank the Office of Naval Research, in particular Mr. Steve Linder, Director, Manufacturing Technology Program, for his support of this effort to develop the first Shipyard Production Process Technologies State of the Art Report. The Best Manufacturing Practices Center of Excellence, Mr. Ernie Renner, Director, and Dr. Anne Marie T. SuPrise, Deputy Director, should also be recognized for their leadership, dedication, and commitment to

producing a quality report in a short period of time. The active participation of the Gulf Coast Region Maritime Technology Center, Institute for Manufacturing and Sustainment Technologies, National Center for Excellence in Metalworking Technology, and Navy Joining Center have been crucial to the success of this endeavor. The core team of people who worked diligently to make this happen are listed below. Their dedication, persistence, leadership, and expertise are to be commended. Their efforts will likely result in a Sate of the Art Report concept that can be improved upon and expanded to include the MARITECH ASE Major Initiatives in the future.

Core Team Members:

John Carney, Office of Naval Research
Tommy Cauthen, Ingalls Shipbuilding
Scott DeVinney, General Dynamics, Bath Iron Works
Suren Dwivedi, University of Louisiana
Tom Hite, Applied Research Laboratory, The Pennsylvania State University
Lee Kvidahl, Ingalls Shipbuilding
Rick Nelson, General Dynamics, Electric Boat Corporation
Mark Panosky, General Dynamics, Electric Boat Corporation
Allan Roy, Newport News Shipbuilding
Bart Sickles, Concurrent Technologies Corporation
Charles Tricou, Applied Research Laboratory, The Pennsylvania State University
Matthew White, Navy Joining Center/ Edison Welding Institute

Short Descriptions

SHIPYARD PRODUCTION PROCESS TECHNOLOGIES (SP-16 PANEL) (Material Management/Steel Outfitting Manufacturing and Assembly)

Item	Page

Cable Pulling 31

Pulling (or installing) electrical cables that support shipboard services involves a majority of manual processes that have changed little over time. Routing the wide range of electrical cable sizes that make up the ship's power, communications, and generation services can typically involve miles of cabling. A majority of the electrical services for military combatants includes large diameter, high voltage shielded cabling that runs hundreds of feet between connection points. Recent practices have introduced fiber optic cabling for low voltage communications systems.

Hydrostatic Testing 32

Hydrostatic testing (or hydro-testing) involves pressurizing specific ship components or systems to determine and validate their structural integrity. Most piping systems on ships are hydrostatically tested to 1.5 times their operating pressure before they are placed into service. Testing involves isolating a component from adjacent ship systems (e.g., tank or piping system); connecting and applying air or water pressure; and identifying potential leaks using leak detection devices. The process is iterative until the complete system achieves the required integrity. Testing guarantees system integrity and, ultimately, the crew's and ship's safety.

WELDING TECHNOLOGIES (SP-7 PANEL)

Beveling 34

Beveling is a process that prepares material surfaces (e.g., plate edges that form a joint) for welding to ensure a quality full penetration weld or, in some cases, the correct depth of penetration. In addition, this angular edge preparation permits greater access to the root of the joint and easier manipulation of the welding torch. Beveling is achieved for block assembly, erection beams, and other subsequent welding practices through milling, grinding, and cutting machines.

Item	Page

Fitting 35

Fitting is the alignment and placement of parts to be welded. This process is one of the most important operations for cost effective welding. The overall dimensional accuracy of ship structures is directly related to the accuracy and adequacy with which parts are aligned prior to welding and held in position during the welding operation.

Shielded Metal Arc Welding 36

Shielded metal arc welding is a process that produces coalescence of metals by heating them with an arc between a covered metal electrode and the work pieces, and obtains shielding from the decomposition of the electrode covering. Although it is one of the oldest arc welding operations, this process is also one of most durable for structural and pipe applications.

Gas Metal Arc Welding 37

Gas metal arc welding is a process that produces coalescence of metals by heating them with an arc between a continuous filler metal electrode and the work pieces, and obtains shielding entirely from an externally supplied gas. This process is a primary method for fabricating ship structures, and is used extensively for piping and pressure vessel components.

Flux Cored Arc Welding 38

Flux cored arc welding is a process that produces coalescence of metals by heating them with an arc between a continuous filler metal electrode and the work pieces, and obtains all or partial shielding by a flux contained within the tubular electrode. One advantage of this process is its ability to weld through pre-construction paint primers with an acceptable weld quality, making it the process of choice in many shipyards.

Item	Page

Submerged Arc Welding 39

Submerged arc welding is a process that produces coalescence of metals by heating them with an arc (or arcs) between a bare metal electrode (or electrodes) and the work pieces, and obtains shielding by a blanket of granular, fusible material on the work piece. By using special equipment, shipyards have refined this technique so that all welding can be performed from one side and the cost of turning completed panels is avoided.

Gas Tungsten Arc Welding 40

Gas tungsten arc welding is a process that produces coalescence of metals by heating them with an arc between a non-consumable tungsten electrode and the work pieces, and obtains shielding by a gas. The process produces superior quality welds and can be used to weld almost any metal. Its ability to independently control the heat source and filler metal additions provides excellent control of root pass weld penetration for critical applications.

Stud Welding 41

Stud welding is a process that produces coalescence of metals by heating them with an arc between a metal stud or similar part and the work pieces. This process can be performed manually with the use of a hand-held welding gun or by mechanized equipment for high production applications.

Electrogas and Electroslag Welding 42

Electrogas welding is a process that produces coalescence of metals by heating them with an arc between a continuous filler metal electrode and the work pieces. Electroslag welding is a process that produces coalescence of metals with molten slag that melts the filler metal and the surfaces of the work pieces. Although their use is declining due to new ship designs and alternative methods, these high deposition processes are gaining popularity in the bridge and building construction industries.

Item	Page

Plasma Arc Welding 42

Plasma arc welding is a process that produces coalescence of metals by heating them with a constricted arc between an electrode and the work piece (transferred arc), or between the electrode and the constricting nozzle (non-transferred arc). Shielding is obtained from the hot, ionized gas issuing from the torch which may be supplemented by an auxiliary source of shielding gas. This process has proven to be very robust for high volume automation welding operations due to its recessed tungsten electrode, which provides longer operating times.

Brazing 43

Brazing is a process that produces coalescence of materials by heating them to the brazing temperature in the presence of a filler metal having a liquidus above 840°F (450°C) and below the solidus of the base metal. This process differs from other joining methods in that the brazing does not melt the base metals being joined, thereby allowing dissimilar or difficult-to-weld materials to be joined.

Laser Welding 44

Laser welding is a process that produces coalescence of materials with the heat obtained from the application of a concentrated coherent light beam impinging on the joint. The high speed, low heat input, and precision of laser welding result in low thermal distortion. With the advent of using fiber optics to transport the light beam to the work, rather than having the part move under the beam, possible applications for laser welding include in-situ repair work, beam to plate joints, and pipe welding.

Electron Beam Welding 45

Electron beam welding is a process that produces coalescence of metals with the heat obtained from a concentrated beam composed primarily of high velocity electrons impinging on the joint. The process features three basic methods: high vacuum; medium vacuum; and non-vacuum — the latter of which is the most practical in the shipbuilding industry.

Section 2

Shipyard Production Process Technologies (SP-16 Panel)

CHAPTER SUMMARY

In this SOA report, steel outfitting manufacturing and assembly addresses more than 20 discrete shipbuilding processes. The objective is to produce a single source of information that provides an overview of processes and a comparison with world-class practices. For steel manufacturing and assembly which is the heart and soul of shipbuilding, the State of the Art is healthy. Despite lower volumes of steel throughput compared to overseas competitors, U.S. shipbuilders are reasonable well equipped. Additionally, industry reflects a trend to purchase services outside of its more traditional role. The transition toward outsourcing is driven by a reliance on fewer U.S. Navy contracts and virtual no commercial work. As a result, production practices in areas that traditionally manufacture piping, sheetmetal, electrical components, and painting have lost the expertise once common across the industry.

While technical advancements continue to affect the information and data that drives production as well as the hardware that steers productivity, there are other less notable changes which are equally important. Moving toward a green industry that is ecologically more responsive to local communities will require vigilance and money. Powder coating as a production process will continue to gain favor, in lieu of traditional paint processes that release air borne contaminants. Reducing production costs for processes that ultimately drive customer contract pricing will hinge on eliminating non-value added operations. Increasing part and, therefore, assembly accuracy are critical to this objective. Currently, there are many production steps that can be considered iterative, largely due to the fit-and-finish qualities of interim products which eventually become the ship. Improvements in producing dimensionally accurate piece parts during each step of the manufacturing process which reduces downstream assembly costs are vital in decreasing overall costs. Investments in cutting, forming, joining, and inspection technologies which perform faster with greater accuracy will become necessary.

Strategies affecting the supply chain must become leaner by reducing inventory levels and work-in-process. Beginning with secondary sources that feed higher tiers of the national supply chain as well as within the internal shipbuilding production processes, just-in-time will become inevitable. Enterprise resource planning and materials requirement planning will continue to be the foundation for changes to the internal functionality of the shipbuilder industry. Investments in computer-based modeling to simulate changing circumstances will also provide informed feedback for key business managers.

Material Management

Material Handling

INTRODUCTION:

Material handling refers to the handling, storage, control, and flow of materials throughout a facility. A material handling system provides efficient flow paths, coordinates supply and demand, minimizes damaged goods, and maximizes storage space. Pre-assembling the parts can also help reduce material movement costs. The successful operation of any enterprise depends to a great extent on an efficient and effective system. In shipbuilding, material handling accounts for a substantial portion of the total ship construction cost.

STATE OF THE INDUSTRY:

Material handling can be categorized into four areas: (1) shop material handling, (2) ship block material handling, (3) ship movement, and (4) movement of small parts and tools in on-board and on-block environments. In shop material handling, the shops rely on forklift trucks, conveyors, and cranes to move material. In ship block material handling, the ship is assembled by using special transporters and cranes (Figure 2-1). In ship movement, the ship/ship systems are moved by using dry docks, tugboats, or pontoon launchers with translation rail systems. In the movement of small parts and tools in on-board and on-block work environments, personnel travel from the work site to another location to obtain these items.

STATE OF THE ART:

Best material handling practices enable shipyards to stationize personnel and minimize the use of less efficient material handling schemes. Most shops

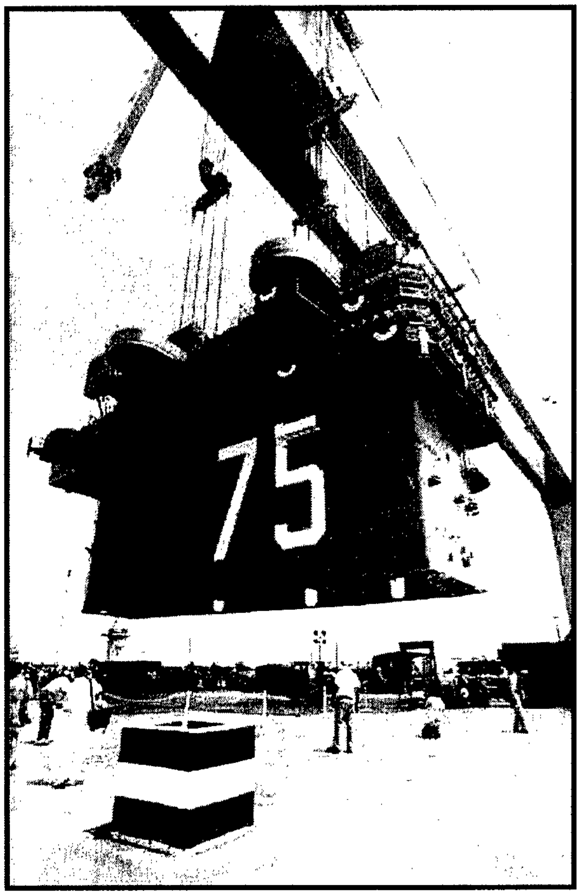

Figure 2-1. Crane Lifting Aircraft Carrier Island House

extensively use power roller conveyors, robotics, and other automated material handling devices. In on-block work environments, larger capacity transporters and cranes provide the means for lifting large blocks, which reduces the number of trips needed to complete block erection. In on-block work environments, material elevators, rather than cranes, are used for transporting smaller loads. Additionally, support services (e.g., storerooms, tool rooms) are being designed as moveable modules and placed near ships, thereby reducing the travel distances for materials.

STATE OF RELATED INDUSTRY:

For this area, further evaluation and collaboration is underway.

ENABLING TECHNOLOGIES:

Simulation modeling is the most advanced tool of material handling planning. This technology enables shipyards to predict future material handling bottlenecks. By resolving these obstacles, shipyards can improve their resource utilization. Simulation modeling is also used to monitor numerous material handling factors; review multiple options; and analyze the cost impact of these options on the entire shipyard system. While it does not provide an optimum solution, simulation modeling does offer a platform for quick review of proposed improvements.

MANUFACTURING STRATEGIES:

An important methodology for improving material handling involves the reduction of movement throughout a shipyard. In a just-in-time (JIT) system, material is manufactured or delivered at the last possible moment; hence, the name. This strategy results in reduced movement of material; less storage space requirements; decreased occurrences of lost or damaged material; and lower monitoring and tracking efforts for in-process storage. An immediate financial benefit of using a JIT system is the availability of operating capital. Rather than tying up millions of dollars in idle material at a shipyard in-process bank, this capital can be invested elsewhere.

Monitoring and Tracking

INTRODUCTION:

Monitoring and tracking refers to systems that detect, follow, oversee, and/or record the location or state of material within a facility. Flexibility and integration are also valuable features for continuous monitoring and tracking systems, enabling facilities to easily adapt to new objectives and/or situations.

STATE OF THE INDUSTRY:

The Automatic Tooling Inventory Control Tracking System (ATICTS) was implemented during the 1980s. ATICTS can track usage and maintain inventory levels which are initially set by the system administrator. By using this system, shipyards can identify low inventory items as well as produce reports that document usage and history. Among the types of reports generated by ATICTS are vendor history, unit prices, cost data, and daily issue from tool areas. In addition to ATICTS, shipyards use barcoding on component material to identify the last location and process which the part has completed. This method can even locate parts in transit.

STATE OF THE ART:

For this area, further evaluation and collaboration is underway.

STATE OF RELATED INDUSTRY:

Heavy industry has developed a generic concept for cell control based on information flow and functional analysis of operations for production cells. Known as ROB-EX, this software control system offers users many functions and applications. Among them are transfer-of-production data; detailed scheduling of work tasks; execution of work tasks; automatic data acquisition; and monitoring which includes production reports.

ENABLING TECHNOLOGIES:

Barcode scanning technology and computer software products provide the means for monitoring and tracking tools and component material. The entire process operation can be optimized by combining ease of performance with accurate on-line tracking of assemblies and elements in production. ROB-EX has already demonstrated its usefulness in many industrial applications and requirements. This software control system facilitates the integration of heterogeneous production cells and systems within an organization. As a result, ROB-EX has great potential in the shipbuilding industry and its applications need to be explored.

MANUFACTURING STRATEGIES:

The foremost requirements of setting up better monitoring and tracking systems are flexibility, integration, and distribution. Flexibility means that the system (e.g., information, control, inventory, accounting) can be quickly adapted to new circumstances and that activities can be changed or re-engineered. The user should also be able to simulate the impact. Integration means that the system can be monitored in all aspects of design, and that the construction, outfitting, and impact of scheduling changes at other shipyards can be assessed. All suppliers should also be included to link the elements of the enterprise. Distribution means that the system aids in accessing different activities in the shipyard. As a result, workflow and scheduling can be adjusted.

Another strategy is to devise a performance measurement control system to track and control progress, thereby measuring activities that affect manufacturing (e.g., internal customer/supplier relationships; external customer/supplier relationships; Pareto charts; SPC charts). A tracking system also needs to provide control mechanisms which maintain progress and provide insight to potential problems through leading indicators, and a closed-loop feedback system to enable corrective actions.

Statusing

INTRODUCTION:

Statusing refers to the timely and comprehensive measuring of a progress, independent of calculating input or observing variances. This operation involves periodic reviews of a process (e.g., material handling, monitoring, tracking) in terms of its current state/condition and the efficiency of its cost factors during execution. From this data, facilities can explore possible corrective actions to improve their processes.

STATE OF THE INDUSTRY:

Statusing involves reviewing a project's progress based on an array of parameters. These parameters may include schedule performance, cost performance, cost statusing, resource statusing, and statusing by variables (e.g., weight, noise). Based on surveys, department managers determine the parameters of their projects' progress, and then discuss these findings at status meetings. Although cumbersome or repetitive at times, statusing can be very insightful and efficient because of the quick interaction among the participants. Additionally, the effectiveness of the process is dependent on the knowledgeability of the participants.

STATE OF THE ART:

Successful organizations use computerized systems which provide information that is timely and synthesized to a minimal number of key business metrics. The most advanced systems will display lower level data that focuses on the business metric corresponding to under performance.

STATE OF RELATED INDUSTRY:

For this area, further evaluation and collaboration is underway.

ENABLING TECHNOLOGIES:

Enterprise-wide management systems are one of today's most effective status-providing tools for upper and middle management. These systems provide status information via databases that are accessible through either the Internet or the Intranet.

MANUFACTURING STRATEGIES:

A novel approach for statusing is the use of a common communications framework such as the Internet or the Intranet. A company creates a link, known as a project team status wall, to its existing website. Only the project's members have access to

the overall group's area. Members can log onto the site and input the status reports pertaining to their tasks. Members also have write/read access to their own tasks, but read-only access to everyone else's. This approach of centralizing data reduces time, effort, and costs associated with traditional methods (e.g., arranging meetings, contacting project members). Statusing via a common communications framework provides time-to-time updated reports from any location at any given instant.

Steel Outfitting Manufacturing Assembly

Beveling

INTRODUCTION:

Beveling is the process of preparing the edges of production piece parts (e.g., plates, shapes) for welding to other parts. This process involves cutting, milling, or grinding the part's edges to an angle (excluding normal or square to the part) most conducive to efficient welding. Beveling is often a secondary operation whereby a part is fabricated with square-cut edges and then later beveled. Bevel geometry is determined by the weld joint design/geometry, part thickness, and planned welding process and position. The geometry can also include single-side, knife-edged bevels (top or bottom edges); single-side bevels with a nose; double bevels (top and bottom edges); bevels with chamfers; J bevels; and U bevels.

STATE OF THE INDUSTRY:

State of the industry for beveling plate and profile parts will be described separately. The various processes for beveling plate parts by shipbuilders will be described first:

- Numerical control (NC) contour beveling is performed by an NC burning machine equipped with a cutting torch, whose bevel angle is controlled by the NC data and varied in real time as the part is cut. This method allows multiple bevels with different geometry and changing inclines to be cut in an automated manner during the plate part's primary fabrication operation. Plasma arc cutting is the cutting process most commonly used. NC contour beveling is generally limited to single-sided, knife-edged bevels. Double bevels and bevels with noses can be cut, provided the parts are bridged or stitched together to prevent movement of the parts between the initial and subsequent torch passes.
- Triple torch NC beveling is performed by an NC machine equipped with three torches mounted on a single tool carriage. One torch remains vertical to perform a square cut, while the other two torches can be adjusted to cut bevels of varying angles and directions. Torch adjustment is manual and remains constant while the torch is moving. If the bevel geometry changes, the cut must be paused and the torch angles manually adjusted. Oxy-fuel burning is the cutting process used, and the bevels are cut during the part's primary fabrication operation. Although slower than CN contour beveling, triple torch burning is much more versatile and can cut single bevels with a nose; single bevels with a nose and a chamfer; and double bevels all in a single pass.
- Mechanized beveling is performed by mechanized torch carriages which run on tracks installed parallel to the cut to be beveled. This method is also a secondary operation. After a plate part is NC cut with square edges, it is moved to another work station where a track is installed, a carriage set-up, and the torch(es) are manually adjusted to provide the desired bevel geometry. An operator monitors the job and adjusts the torches as needed. Oxy-fuel burning is the cutting process used.
- NC milling is used in limited specialized applications such as preparing plates for one-sided welding. Milling is limited to straight parallel edges, but can perform a variety of complex edge preparations including double bevels, bevels with chamfers, J bevels, and U bevels. Milled edges are extremely accurate with sub-millimeter tolerances.

In beveling other ship production material, the processes are similar. Profile beveling (or beveling structural shapes that include tees, angles, channels, or flat bars) is being performed using robotic technology. Automated profile beveling is performed during the primary cutting operation using robots equipped with either oxy-fuel or plasma cutting techniques. Manually cut profiles are beveled using mechanized equipment, if the profiles are large enough, and with hand torches (oxy-fuel), if not. Some small profiles are beveled manually using hand-held grinders as a secondary operation, either in the shop or in the field.

STATE OF THE ART:

The current state of the industry in beveling is near the state of the art. Advanced cutting methods such as waterjet cutting, high definition plasma cutting,

and laser cutting could be utilized in primary and possibly secondary beveling operations; however, capital costs for these methods are high as specialized equipment and training is required. In addition, these methods are shop operations so they would be unsuitable for filed applications. But despite the cost, these new beveling processes greatly improve accuracy. In cases where tolerances are not critical, the assemblies can be processed using traditional beveling methods.

STATE OF RELATED INDUSTRY:

The state of related industry is the same as the state of the art for beveling.

ENABLING TECHNOLOGIES:

NC contour beveling requires a means to embed the beveling data into the NC cutting data. Generally, bevel data is developed in the electronic design or product model based on the weld joint's design and physical geometry. The bevel data would then be extracted with the NC contour for nesting and burning.

MANUFACTURING STRATEGIES:

A key strategy for efficient beveling is to cut neat parts that are beveled during the initial fabrication process. This approach allows bevels to be cut with efficient mechanized or automated equipment, and provides a more accurate, higher quality cut at a lower cost than beveling at fit-up on a platen or a ship.

Cutting

INTRODUCTION:

Cutting is the process by which structural and outfitting piece parts are fabricated from their raw stock material. Structural steel is generally cut using a thermal cutting process such as oxy-fuel flame, plasma arc, or laser beam cutting. For plasma and oxy-fuel cutting, the torch is moved along the cut path by a variety of means including manually (hand torch), mechanized equipment, numerical control machines, and robotics.

STATE OF THE INDUSTRY:

State of the industry for cutting plate and profile parts will be described separately. The various processes for cutting plate parts by shipbuilders will be described first:

- NC cutting of plate parts is by far the predominate process used by shipbuilders. Both plasma arc and oxy-fuel processes can be used depending on plate thickness. Generally, plates less than one-inch thick are cut using plasma arc because of its higher cutting speeds and superior edge quality. NC cutting produces the most accurate parts at the highest levels of productivity. NC cut parts can be cut square to be beveled later, or beveled using triple torch oxy-fuel or contour bevel plasma arc cutting technology (Figure 2-2).

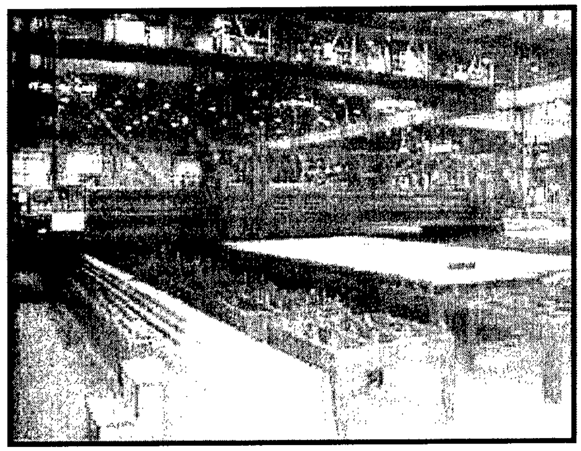

Figure 2-2. 30-Foot Burning Machine

- Mechanized cutting, in the shop, is generally limited to rectangular parts. Gantry mounted mechanized machines equipped with multiple torches are used to strip plates into rectangular parts with parallel edges. Oxy-fuel is the most common process used on mechanized machines. These machines can produce square and beveled cuts. Torch separation (part width) can be set manually or dialed-in on more modern machines. Mechanized cutting is also used for trimming parts after shaping when a scribe line is applied from a mold; a track is set up parallel to the scribed edge; and an operator manually adjusts a torch carried by a mechanized carriage as it moves down the track. Mechanized cutting with tracked carriages is commonly used for making cuts in the field.
- Optical follower cutting equipment is still used for fabricating small parts. An optical follower utilizes a sensor that follows the contours of a full-size drawing of the part. One or more torches then repeat the path of the optical follower to produce single or multiple copies of the part. Either plasma arc or oxy-fuel process can be used. The parts are generally square cut.
- Hand torch burning is rarely used to fabricate (cut) plate parts in the shop. Hand torch burning, both plasma arc and oxy-fuel, are commonly used for a broad range of cutting activities in the field.

Profile cutting is performed by automated robotic cutting lines or manually with hand torches. Robotic profile cutting is more accurate and productive than manual cutting, and can feature both plasma arc and oxy-fuel processes for beveled or square cuts. Manual cutting of profile parts is still the predominate method of cutting profile parts in many shipyards. The oxy-fuel process is generally used. This method requires the parts to be laid-out (or measured) with the end-cut features drawn on the part prior to cutting. Manual cuts usually require grinding to achieve the requisite cut quality.

STATE OF THE ART:

NC cutting is the preferred method of delivering state-of-the-art cutting processes. Advances in cutting technology are primarily in the cutting processes. The state of the art is advancing by making the faster, higher quality, more accurate cutting processes such as laser, waterjet, and high-definition plasma applicable to thicker material. Laser cutting is generally accepted as the most accurate, highest cut quality cutting process. In years past, laser cutting was limited to sheet metal. Current laser technology is capable of cutting material up to 30-mm thick. New developments promise even greater capabilities at lower capital investments, making laser cutting a more attractive option for shipbuilders.

Waterjet cutting can leave irregular kerfs when speeds and thickness are increased. This situation can be avoided by reducing the speed of the cut; however, production rates will be drastically reduced. Waterjet machines are typically stationary, and can require high maintenance.

Cutting tools must have high hardness and stiffness to resist deformation under the high cutting forces exerted in machining operations. These tools must also be high-wear resistant to maintain sharp cutting edges and permit high machining accuracy over extended periods of time. Laminated ceramic composite cutting tools have been developed which demonstrate improvements in strength, toughness, and thermal shock resistance compared to conventional, non-laminated ceramic composites.

STATE OF RELATED INDUSTRY:

Related heavy manufacturing industries (e.g., farm and construction equipment) have embraced laser cutting technologies, and are working to take full advantage of their improved accuracy to reduce downstream fitting and welding costs. These industries are also moving toward fully automated NC cutting cells which can load raw stock, execute cutting programs, and off-load the finished parts and scrap without human intervention. These cells promise around-the-clock, unmanned operation, thereby further reducing the cost of production.

ENABLING TECHNOLOGIES:

Computer numerical control (CNC) and direct numerical control (DNC) automated cutting stations provide the highest accuracy, quality, and productivity. While there are many different generations of equipment in use, the most modern cutting stations provide enhanced accuracy and control including self-diagnostics. Automated cutting depends on the availability of NC cutting data that can be developed using a variety of computer aided design/computer aided manufacturing (CAM) tools. In addition, continuing advances in laser technology may result in the cutting of thicker materials in the near future.

MANUFACTURING STRATEGIES:

The process of delivering, loading, and unloading material to different cutting stations requires a great deal of coordination, particularly when a wide range of plate sizes and thicknesses exist. To minimize the amount of labor spent on these non-value added activities, many shipyards are combining the advantages of continuous flow manufacturing (CFM) and JIT manufacturing. By successfully controlling the planned flow and manufacture of materials as they move through the cutting process, these strategies promise to eliminate multiple handling and storage of parts cut in advance of their need.

Forming

INTRODUCTION:

There are two types of forming processes: hot and cold. Both are regarded as expensive and cumbersome manufacturing processes which rely on a combination of manual and semi-automatic operations. For hot forming, each part made requires a set of forming dies (male/female) that represent a part and its configuration. To form the part, the material undergoes a series of heating and pressing operations until the final shape is achieved. If the material is manipulated outside its temperature parameters, then its properties will be altered and the material will have to be replaced or annealed/tempered. For cold forming, the operation excludes the heating step.

STATE OF THE INDUSTRY:

In searching for a more economical and faster way to produce these parts, shipyards developed cold forming techniques using existing equipment. In addition, multi-functional dies can readily be made in-house at a fraction of the cost of hot forming dies. The female die is used for a wide range of part sizes, and the male die is used for parts within a specific range of radii. To manufacture a part, the press operator gradually rotates and presses the material until the desired shape is achieved. Validating the accuracy of these shapes is confirmed using radius gauges, hand sweeps, or molds. The scale of certain items undergoing cold forming often relies on more advanced accuracy control using photogrammetry and laser-coupled theodolites. Although some parts must be produced through hot forming techniques, companies can expand their capabilities by developing cold forming techniques. This approach enables companies to perform in-house manufacturing, reduce outsourcing, decrease production costs, and improve quality.

The size and thickness of the material being processed limits typical shipyard forming capabilities. Components that require close tolerances use CNC press or rolling machines (Figure 2-3), which often feature the mechanical means to position and form the material. Unlike forming thin sheet-metal materials as used by automotive and air-frame industries, forming thick section large components requires larger, less accurate machines. The ability to achieve and maintain high levels of accuracy translates into repetitive operations and greater downstream costs when straightening distortion becomes necessary. If tolerances are not critical, thicker material sections can be processed using the traditionally older forming equipment found at shipyards.

STATE OF THE ART:

For this area, further evaluation and collaboration is underway.

STATE OF RELATED INDUSTRY:

For this area, further evaluation and collaboration is underway.

ENABLING TECHNOLOGIES:

As a primary operation, forming has changed very little, largely due to the low volume production of relatively subtle compound shapes found in shipbuilding. Newer CNC equipment capable of providing greater precision and dimensional control

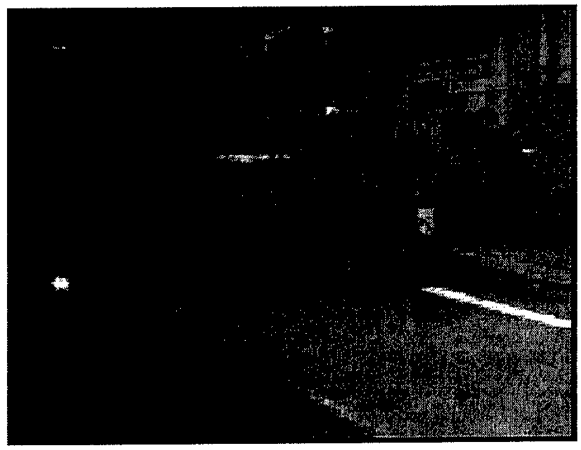

Figure 2-3. Rolling Machine

are available in the market place and, when coupled to product model electronic data, can replicate exact surface development required by ship designers.

The ability to accurately measure and determine the fairness of rolled or formed shapes has been enhanced by modern industrial measurement techniques. Using theodolites, coordinate measuring machines, and other similar devices, shipbuilders can now determine and validate the consistency of formed parts. These capabilities did not previously exist across the industry.

MANUFACTURING STRATEGIES:

For the shipbuilding community, forming operations occur shipboard as well as in the supporting manufacturing shops. Although strategies may differ, the principle objective is aimed at defining similar work content that is compatible with production capacity. Another factor is the ability to maintain a certain range of flexible manufacturing, while still arranging production equipment into manufacturing cells to support the principle of continuous flow. Rather than cluster similar operations in specific areas, the arrangement of the equipment should be dictated by the work content and the operations needed to produce a family of parts. This approach would maximize production capacity.

Punching and Drilling

INTRODUCTION:

Punching and drilling are similar production processes that create holes in substances by using equipment to remove excess material. Punching uses forceful, repeated blows to pierce through the material,

while drilling uses cutting bits to bore through the material. Piece part fabrication relies on these processes to provide certain design details which cannot be executed by other means.

STATE OF THE INDUSTRY:

Punching and drilling operations trace back to traditional drop forging, where brute force molded, shaped, and pierced the materials designed to be joined with others. The precision and accuracy of such operations often had significant, unacceptable variability. Modern shipbuilding has witnessed significant changes in the ability to accurately process material in production. As ship designs became more complex, the accuracy in piece part fabrication became more important. This event lead to corresponding changes in the functionality and accuracy of production equipment for punching and drilling. The importance of controlling the position, location, size, and quality of edge cut when manufacturing piece part for steel, sheet-metal, or piping becomes critical to downstream assembly operations, if cost is to be controlled. Today, many shipbuilders maintain one or more drilling and punching machines. Many of the large capacity machines (Figure 2-4) are older and, therefore, lack any sophisticated control. There is evidence that many yards are using CNC punching machines as well as milling machines in production.

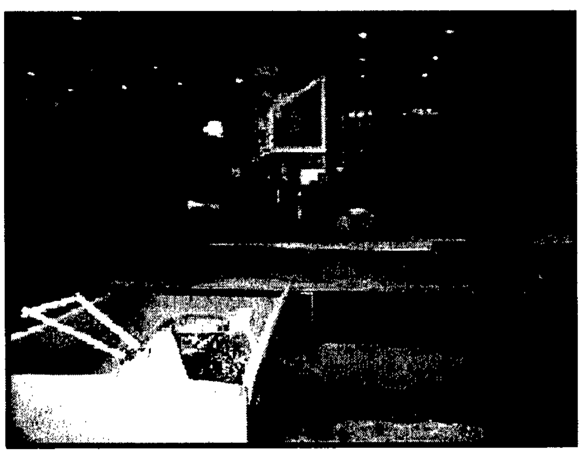

Figure 2-4. Drilling Asset

STATE OF THE ART:

The size and thickness of the material being processed limits typical shipyard drilling and punching. Components that require close tolerances would utilize CNC punch presses that have mechanical means to position the plate. The punching action can produce holes or shapes with greater accuracy. If tolerances are not critical and holes have large diameters, CNC burn tables can be used. The burn tables also allow for thicker material sections to be processed. While drilling is not typically performed on many of the parts used in ship manufacturing, standard method such as CNC machining centers, drill presses, and radial arm drills can be used.

Although these processes have not undergone any revolutionary changes, there have been many advancements in the materials and consumables that perform these functions. Today's drill bits feature coatings which increase their tool life and produce more accurate features. These bits also have been ported for high-pressure coolant, which allows for chip removal from the cutting face. This method provides greater feed rates while drilling, thereby increasing production. The quick-change carbide insert bits also allow for fast and easy replacement. Punching equipment has significantly reduced in size without sacrificing capacity. Inexpensive units can be placed throughout manufacturing facilities to expedite the punching process for small features and individual manufacturing requirements.

STATE OF RELATED INDUSTRY:

The state of related industries is the same as the state of the art in punching and drilling.

ENABLING TECHNOLOGIES:

As secondary operations, punching and drilling have undergone a significant transformation. The removal of material to create accurate and precise holes is being performed in a variety of ways in modern shipbuilding. CNC plasma arc, oxy-fuel, laser, and waterjet cutting are current processes used within the industry to cut holes. Portable and radial-arm drilling machines are still used with less accuracy, as are manual hydraulic punches along with plasma and oxy-fuel cutting machines. CNC boring and milling machines, prevalent in most modern machine shops, provide the ability to produce piece parts with great accuracy.

MANUFACTURING STRATEGIES:

For the shipbuilding community, punching and drilling operations occur shipboard as well as in the supporting manufacturing shops. Although strategies may differ, the principle objective is aimed at defining similar work content that is compatible with production capacity. Another factor is the ability to

maintain a certain range of flexible manufacturing, while still arranging production equipment into manufacturing cells to support the principle of continuous flow. Rather than cluster similar operations in specific areas, the arrangement of the equipment should be dictated by the work content and the operations needed to produce a family of parts. This approach would maximize production capacity.

Shaping

INTRODUCTION:

Shaping is a process that affects a variety of material types and manufacturing operations. Essentially, shaping involves production processes that enable the shipbuilder to create complex three-dimensional surfaces, generally from flat stock material. Additionally, shaping refers to the contouring of flat stock material into irregular geometric shapes. Piece part fabrication relies on shaping processes such as pressing, rolling, line heating, and folding machines to provide certain design details that cannot be executed by other means.

STATE OF THE INDUSTRY:

Shaping relies on a variety of process equipment to achieve design requirements that meet ship specific needs. Like punching, the precision and accuracy of shaping operations often had far greater variability than what was acceptable. Modern shipbuilding has witnessed significant changes in the ability to accurately process material in production. The importance of controlling the position, orientation, location, size, and finish quality of shaped parts when manufacturing piece part for steel, sheet-metal, or piping becomes critical to downstream assembly operations, if cost is to be controlled.

STATE OF THE ART:

For this area, further evaluation and collaboration is underway.

STATE OF RELATED INDUSTRY:

For this area, further evaluation and collaboration is underway.

ENABLING TECHNOLOGIES:

Utilized as either a primary or secondary process, shaping operations have undergone a significant transformation. Developing 3-D shapes of material generally engages several steps to achieve a final product. As a result, shaping is both art and science, where science may provide only part of the solution. The scale of piece part undergoing this process dictates the degree of accuracy achieved. Controlling the process to ensure the best results relies heavily on accuracy control and measurement equipment. Whether bumping material on a manually operated press or roll forming larger flat stock into compound shapes, control is critical for cost efficiency. Alternate methods, such as line heating which involves localized thermo forming to achieve shape in small and large parts, tend to add excessive cost to the overall process particularly when employed as a distortion control measure.

MANUFACTURING STRATEGIES:

For the shipbuilding community, shaping operations occur shipboard as well as in the supporting manufacturing shops. Like other manufacturing operations, shaping will continue to be part of the overall ship production process. However, minimizing complex parts in ship designs ultimately reduces the variability and cost associated with this process. Applying the principles of Design for Manufacturing and Assembly (DFMA) is crucial to better manage the cost of unique low volume parts. Pressing and forming materials, where material is displaced beyond its yield point, achieve more consistent and predictable shapes than thermal forming processes.

Heating

INTRODUCTION:

Heating is a secondary process traditionally reserved for material items that will undergo forming and straightening operations. The practice of heating materials to enable improved forming is more an art than science. During the past 20 years, modern shipbuilding has introduced new generations of materials that differ somewhat from conventional mild carbon steels. As a result, different construction techniques, such as heating, have been developed to produce the compound shapes and forms required by the designer. The introduction of higher strength steels (e.g., AH, DH) and alloys (e.g., High Strength Low Alloy [HSLA]; High Yield [HY] 80 and 100 ksi steels) for specific applications in shipbuilding has exacted the need to master how and when heating can be an effective process to employ. Shaping, forming, pressing, and welding these materials often relies on heating processes or hot work to achieve desired contours and compound shapes, or to straighten distorted members. One process, line heating, uses acetylene torches and a series of pattern zones to

produce complex parts with relative ease and efficiency. This method is found in commercial overseas shipbuilding, where mechanics knowledgeable in how to control the surface development of a part using heat are particularly revered.

STATE OF THE INDUSTRY:

Heating, as a process in manufacturing, is generally considered an integral, secondary operation. As a means of controlling either mechanical or weld distortion, heating is commonly used during the assembly phase of construction. Unfortunately, controlling distortion at this point adds consider rework and often repair to surrounding areas that have been painted or insulated. Ideally, the process of heating to correct for excessive deflection should be avoided through process and accuracy control techniques. Within manufacturing, heating may be the process of choice during small part fabrication to enhance forming operations. Heating may also be necessary to reduce residual stresses in raw stock as well as material items that have already undergone some manufacturing. To accomplish this, there are a variety of techniques available including free-forming using hand torches, larger ovens, furnaces, or autoclaves.

The ability to monitor the degree of forming or shaping material using heating as the process often requires hand scribes. These scribes (or pantographs) are capable of tracing a series of grided patterns uniformly across compound surfaces. As the heating process continues to change the shape of the item, mechanics check and recheck the accuracy of their work. Unfortunately, this process is virtually all manual, and relies on a few skilled tradespeople knowledgeable in controlling the results of heat forming. Unless the need for absolute precision arises which would require expensive CNC equipment and scarce skilled fabricators, line heating will continue to be a special process step in shipbuilding. The ability to achieve and maintain high levels of accuracy translates into repetitive operations and greater downstream costs when straightening distortion becomes necessary. If tolerances are not critical, thicker material sections can be processed using the traditionally older forming equipment found at shipyards.

STATE OF THE ART:

Line heating remains the state-of-the-art method for shaping plate material. The advent of new steels, such as the HSLA-65, has recently spurred investigators to examine the parameters used for line heating these materials. State-of-the-art analysis techniques make it possible to predict and adjust the heating parameters to control the amount of distortion and residual stress development in the assembly. Low heat input welding techniques are gaining acceptance as a viable method for controlling distortion in ship assemblies. Analysis techniques are also capable of prediction the distortion associated with welding so, whenever practical, the distortions may be controlled during fabrication. Induction heating (as opposed to resistance heating) holds great potential for heating material in a shipyard environment such as preheat for welding. This process potentially can reduce heating power consumption, after a significant initial capital investment.

STATE OF RELATED INDUSTRY:

The state of related industry is the same as the state of the art in heating.

ENABLING TECHNOLOGIES:

As a primary operation, heating has changed very little largely due to the low volume production of relatively subtle compound shapes found in shipbuilding. Whether to relieve stresses, improve workability, or coax a form from a flat material, heating remains relatively nondescript in the overall shipbuilding process. While improvements in monitoring fixed ovens enable operators to control heat ranges with greater precision, there are no known technologies that can replace the skill of veteran shipbuilders capable of sculpting complex shapes from flat materials using simple hand torches.

MANUFACTURING STRATEGIES:

For the shipbuilding community, heating processes occur in the manufacturing and assembly operations. Although strategies may differ, the principle strategy aims at defining and selecting the most appropriate application and circumstance to introduce heating as the process of choice.

Shearing

INTRODUCTION:

Shearing is a more traditional process, often reserved for less complex materials where accuracy is not a significant requirement. The process involves the sizing of specific manufactured part dimensions by using powered hydraulic machines. These machines tear the base material along a single axis much like

scissors cutting paper. Typically, shears are manually operated while the material is positioned and held during the shearing process. Part candidates are generally flat sheet stock, ferrous and non-ferrous materials ranging in thickness from light gauge sheet metal to thicker steels approaching 0.75 inch. Depending on the thickness of material, the resulting finished items exhibit non-uniform dimension due largely to the mechanical tearing along one or more edges. This edge tearing results in minor damage to the mechanical properties of the base material and, in some cases, diminishes the quality necessary for welding.

STATE OF THE INDUSTRY:

Because the shipbuilding industry produces large volumes of steel, some of which are used as consumable material, the process of shearing is common. Regardless of the production volume, shearing provides a relatively fast and economical option when manufacturing small, simple, flat parts. Material items (e.g., welding clips, backing bars, gusset plates) must be produced in relatively high volume to support steel assembly and erection. The need to produce such materials has been satisfied using shears as one option. To manufacture a part, the operator positions material into the throat of the shearing machine between the stationary and shearing surfaces; energizes the shearing cycle; and begins to cut the desired material lengths using a temporary stop or reference point usually located on the machine. Shears, like presses, have inherently similar mechanics and can present certain dangers to the operator. The force and speed of operation is generally a function of the shearing tonnage, which is typically lower than high capacity presses found in shipbuilding.

The ability to achieve and maintain high levels of accuracy translates into less downstream costs when straightening distortion becomes necessary. If tolerances are not critical, thicker material sections can be processed using the traditionally older forming equipment found at shipyards.

STATE OF THE ART:

For this area, further evaluation and collaboration is underway.

STATE OF RELATED INDUSTRY:

For this area, further evaluation and collaboration is underway.

ENABLING TECHNOLOGIES:

As a primary operation, shearing has changed very little largely due to the low volume production of relatively simple items such as welding clips, jacks, and other small consumable products typically found in shipbuilding. The introduction of higher speed and more accurate equipment, capable of providing greater precision and dimensional control, are available in the market place. When coupled to product model electronic data, these kinds of manufacturing machines can replicate exact surface development required by ship designers.

MANUFACTURING STRATEGIES:

For the shipbuilding community, shearing operations are located predominately in manufacturing shops. Although strategies may differ, the principle objective is aimed at defining similar work content that is compatible with production capacity. Another factor is the ability to maintain a certain range of flexible manufacturing, while still arranging production equipment into manufacturing cells to support the principle of continuous flow. Rather than cluster similar operations in specific areas, the arrangement of the equipment should be dictated by the work content and the operations needed to produce a family of parts. This approach would maximize production capacity.

Sawing

INTRODUCTION:

Sawing is a manufacturing process where material is cut into specific sizes using abrasive cutting methods. A variety of material types can be cut using different configurations of semi-automated saws and manual saws (e.g., hacksaw). Electrically powered saws range in size, power, throat depth, and orientation (either vertical band saws or horizontal saws). Utilized as either a primary or secondary process, sawing is generally reserved for the fabrication of smaller piece parts where speed and accuracy are less important.

STATE OF THE INDUSTRY:

Sawing has been a traditional process that is applied to a wide range of materials including steel, sheet metal, cabling, insulation, pipe, and other miscellaneous materials. Because sawing relies on abrasive material removal, different configurations of materials and density of cutting teeth have been developed to cut materials more efficiently. Certain model saws feature self-lubricating systems that

improve cutting speeds and reduce abrasive wear and heat. Consumption and repair of abrasive cutting blades, however, tend to influence the economy and accuracy of cutting certain materials.

Within the shipbuilding industry, band and horizontal saws are used for cutting materials that are hand loaded and unloaded. Sawing almost always relies heavily on operator intervention to control and monitor the process. The process lacks the necessary sophistication to permit multiple position cutting without intervention. Coupled with consumables and limited controls, sawing is the least desirable process for fabricating material, particularly when speed and accuracy are important. More efficient cutting equipment and methods have been developed, specifically for the larger flat stock material that has diminished the need for conventional sawing.

STATE OF THE ART:

Sawing is typically used for sectioning items such as bar stock and rod. Most saws used in shipyards are inexpensive; designed for quick and rough cutting; and would be used where thermal cutting is not recommended or possible. In addition, parts to be machined could require saw cuts to eliminate any hardened surfaces.

Today's state-of-the-art saws have greater capacity and are able to handle much larger components. Automatic feeders can be utilized to maximize repetitious production cutting, thereby increasing throughput. In addition, new materials and configurations of the cutting blades increase feed rates which, in turn, increases production.

STATE OF RELATED INDUSTRY:

The state of related industry is the same as the state of the art in sawing.

ENABLING TECHNOLOGIES:

Utilized as either a primary or secondary process, sawing operations have changed little over the past. Do-All and Marvel saws continue their domination in the marketplace; however, some suppliers have integrated additional operations into a sawing work center to complement typical fabrication steps for particular times. Geka, for example, has combined notching and coping along with hole punching and sawing operations into one single ironworker. For the most part, vertical and horizontal band saws predominate. While limited controls are available to improve performance, most sawing machines continue to be manual. In addition, certain raw stock material items will continue to create a need for these machines.

MANUFACTURING STRATEGIES:

Due to the limited need for conventional sawing equipment, there is little evidence that any manufacturing strategy applies. As with other process equipment, similar operations have traditionally been cloistered together without regard to work content or material flow. However, minimizing complex parts in ship designs will ultimately reduce the variability and cost associated with this process.

Disposing

INTRODUCTION:

Disposing involves the storage, handling, and containment control of a wide range of byproducts (solids, liquids, gases) produced during shipbuilding operations. The managing of this wastestream is an integral part of the shipbuilding industry's responsibility. Proper waste management involves many aspects such as identifying safeguards; reducing hazardous exposure; and complying with environmental laws and regulations.

STATE OF THE INDUSTRY:

To ensure proper waste management, an internal team of experts determines the risk, liability, expected cost, and developing viable strategies. This team can also identify and implement waste management programs that minimize environmental exposure and produce the best payback. Conventional practices have included the use of valuable land sites to either dump waste or engage in the practice of sorting and separating different materials. The wide array of shipbuilding byproducts can range from relatively harmless scrap metal to hazardous materials like nuclear waste. Disposal technologies consist largely of dedicated areas where materials can be loaded for transfer to other disposal sites as recognized and controlled by local or regional governments. Reducing the risk and liability associated with the disposing of hazardous and non-hazardous materials have become important goals at many facilities.

STATE OF THE ART:

Disposal of metals is no longer considered a suitable method of dealing with excess or scrap metal. All excess metals are now recycled. Likewise, solvents and oils can no longer be land filled. Solvents and oils are usually fuel blended and burned for their BTU value. However, the best methods for dealing with solvents and oils is to recycle the materials or substitute less hazards materials in their place.

STATE OF RELATED INDUSTRY:

The state of related industry is the same as the state of the art in disposal.

ENABLING TECHNOLOGIES:

Developing and analyzing a best practice to support waste disposal may not necessarily point toward a technological solution without an extremely detailed business case. For example, outsourcing waste hauling may prove to be considerably more attractive financially than continuing hauling waste using internal resources. Identifying and addressing the surrounding issues must be undertaken to determine the type of service needed; the type of hauling equipment required; the availability and cost of local/regional hauling and disposal; and the availability of licensed operators to perform this work. Depending on the situation, the method of payment will either be based by the ton or by a volume measure. In each case, the short and long term economic factors must be evaluated. Methods of payment for disposal can also offer opportunities for cost improvements.

MANUFACTURING STRATEGIES:

Managing the wastestream to ensure compliance with state and federal laws as enforced through regulatory bodies is the only viable operating strategy. Understanding the mitigating circumstances and the requirements necessary to enact policies and procedures that meet interpretation of the law must rely on excellent communication. Establishing and maintaining good communication among the shipbuilding community and between the organizational structure of each shipyard is critical to avoiding penalties and potential shutdowns.

Recycling

INTRODUCTION:

Recycling involves the storage, handling, containment, and reuse of materials that are part of the shipbuilding wastestream. Complying with local and regional regulations as well as the challenge of converting this portion of the industrial wastestream into revenue are integral parts of the shipbuilding process.

STATE OF THE INDUSTRY:

As a maritime industry, shipbuilding has generally been more conscientious about solid waste disposal and recycling than many industries. Effective recycling requires a thorough understanding of the wastestream and waste management activities of any organization. In many cases, recycling mandates can be met cost effectively. However, organizations should be encouraged to recycle for environmentally conscious reasons. This focus will provide intrinsic value to the community and, in return, the organization will strengthen its community relations.

Issues to consider in the analysis of potential recycling programs include:

- Overcoming negative positions in the organization.
- Understanding how waste is generated.
- Understanding how waste is collected and disposed.
- Identifying opportunities to recycle materials within the current collection and disposal system, piggy backing where possible.
- Developing new recycling programs that minimize the impact on normal operations. For example, recycling separation at the source is generally the cheapest way to begin the recycling process.
- Developing and sustaining markets for recycled materials. Organizations should expect volatility relative to material outlets and prices.

In shipbuilding like other heavy industries, there is a considerable investment in materials. Many items are recyclable if provisions for handling and disposing of the material are considered when a process is originally established.

STATE OF THE ART:

The process of recycling metal is necessary because waste material results as a bi-product of machining and cutting operations. All excess metal is collected and sent to a recycler for processing and reuse. Ideally, the use of near-net shape parts would reduce the volume of metal needing to be recycled. Unfortunately, this is not always possible and recycling of the excess metal becomes necessary. Recycling of solvents and oils involves collecting the spent material and processing by various means for reuse. Some solvents and oils cannot be recycled, therefore disposal becomes the only available option.

STATE OF RELATED INDUSTRY:

The state of related industry is the same as the state of the art in recycling.

ENABLING TECHNOLOGIES:

Establishing organizational task teams to prevent and control pollution is an important first step toward increasing the volume of recyclable products. The technologies are unsophisticated for the most part, and range from paper shredders to filtration systems to asphalt, glass, and scrap steel recycling. For example, one shipyard recycled over 7,000 tons of asphalt within a five-year period, and another at more than 4,000 tons of paper and 1,800 tons of cardboard. A drum crushing facility has de-headed and crushed over 70,000 55-gallon drums. In these examples, the facilities were able to eliminated the hauling and disposal fees collected by local landfills.

The process of recycling metal is unsophisticated at the present time. Excess metal is collected and sent to a recycler for remelting. The use of near-net shape parts is one of the best ways to reduce the volume of metal needing to be recycled. Since this is not always feasible with large castings and plates, recycling becomes the only method available. Recycling of solvents and oils can be reduced by substituting existing chemicals with less hazardous products. Many companies exist which specialize in finding safer chemical substitutes that have the same performance characteristics as the material being replaced.

MANUFACTURING STRATEGIES:

An important first step in developing a long term strategy is to establish an organizational team with a vested interest in waste management including waste generation, collection, disposal, and recovery. Managing the process, as well as communicating the importance of proper disposal and recycling, are also fundamentally important to the success of a program.

Inspecting

INTRODUCTION:

Inspection within the shipbuilding industry represents one process with many facades. Whether it involves material receipt or ship system completion, inspection remains an iterative process that requires sophisticated practices similar to those in other industries. Inspection within the shipbuilding industry can also involve highly specialized advanced technologies and services, especially in such areas as manufacturing, assembly processes, and sea trials. In addition, the process of inspecting production material can involve aggressive measures to validate the pedigree of material as well as certifying the functionality or operability of particular ship system equipment. Inspecting dimensional characteristics of both small and large components and assemblies typically involves highly accurate measurement machines that can efficiently compare as-built to as-designed.

STATE OF THE INDUSTRY:

Whether shipbuilding involves military combatants or commercial class designs, inspection plays a vital role in the validation process for both owner and builder. Beginning with material receipt, conventional means to verify quantity, size, material type, potential damage, documentation, warranty, demurrage, and completeness are evident. The inspecting process can be more rigorous when verifying dimensions. Use of coordinate measuring machines is common within the industry. There are also other technologies such as spectroscopy, ultra sound, x-rays, and magnetic resonance that ensure the quality and consistency of materials which safeguard the health and safety of the shipbuilder and shipowner. Material Data Sheets are typically used in the receipt inspection function when consumable materials such as solvents, cleaners, and paints are involved.

STATE OF THE ART:

While non-destructive evaluation (NDE) plays a vital role in shipbuilding validation, it is generally associated with the examination of weldments for assembly soundness. Recently, ultrasonic inspection has gained acceptance as an alternative to radiography for volumetric inspection of material. New time-of-flight ultrasonic techniques hold great potential for truly sizing the through thickness dimension of internal discontinuities, and new ultrasonic record keeping systems provide the necessary audit documentation. Advanced systems such as digital photogrammetry, laser coupled theodolites, interferometers, and 3-D laser scanners have greatly improved the accuracy and efficiency of the inspection of complex objects, up to and including entire ship hulls. In the near future, incremental improvements of these systems are anticipated. These digital measurement systems have enabled near real-time feedback to Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) analysts so that component designs and as-built conditions can be compared, archived, and updated as necessary.

STATE OF RELATED INDUSTRY:

The state of the related industry is the same as the state of the art in inspecting.

ENABLING TECHNOLOGIES:

The inspection process for manufacturing activities is as varied as the broad range of products and operations that define manufacturing. Dimensional accuracy of components remains, however, one of the more important attributes of the ship assembly process. Validating, verifying, recording, and comparing dimensional data that defines the tolerance boundaries for an extensive scope of products is a critical shipbuilding requirement. Innovative technologies (e.g., digital photogrammetry, laser coupled theodolites, interferometers, 3-D laser scanners) enable inspectors to efficiently inspect relatively complex objects with accuracy well beyond what was possible only five years ago. The ability to import digital design data and compare as-built or as-delivered product dimensions allows analysts to determine potential changes to the form, fit, or function of any given component.

As for the documentational side of inspecting, digital records are now archived and transmitted via computer terminals, thereby displacing the burdensome, paper-based records that usually required large storage areas. The ability to communicate inspection information in a timely manner has also improved. Widespread use of electronic mail via Internet, Intranet, fax machines, and other office services can transmit data to multiple viewers quickly and efficiently. Paralleling these electronic transactions is the growing use for computer programs which allow analysts to compile, filter, sort, chart, and perform trend analysis with far greater efficiency than ever imagined.

MANUFACTURING STRATEGIES:

Trends toward self-inspection of work performed are also gaining wider acceptance. However, changes in corporate loyalty and a more mobile workforce tend to mitigate consistency in job performance and work quality. The state of the industry for inspection generally indicates parity with other heavy manufacturing industries. In many instances, inspection documentation within the shipbuilding industry is significantly more thorough compared to the private sector.

Setting and Erecting

INTRODUCTION:

Setting generally refers to a major evolution in the assembly stage of shipbuilding where some combination of positioning and handling operations are involved. Setting and erecting are terms which typically describe those activities that contribute to the final assembly of outfitted structural blocks, the joining of which completes the ship.

STATE OF THE INDUSTRY:

The shipbuilding industry generally utilizes cranes to execute the assembly of ship sections. Setting these sections relies on accurate weight calculations where centers of gravity are determined both longitudinally and latitudinally. To accomplish this task, a rigorous effort to identify and calculate weights and moments is essential. Once this information is determined, a series of subordinate steps must precede any crane lift before setting and joining units can begin. Sizing and locating lifting pads and lugs that best match the arrangement of lifting bridles for different service cranes must also match the ship structure. As cranes lift and position these ship sections or blocks, activities then focus on accurately setting critical features of adjacent components to minimize any significant relocation of structure. Coordination of fitting house-sized blocks demands excellent voice or sight communication as well as a wide array of devices to secure and attach these units to one another.

STATE OF THE ART:

For this area, further evaluation and collaboration is underway.

STATE OF RELATED INDUSTRY:

For this area, further evaluation and collaboration is underway.

ENABLING TECHNOLOGIES:

The primary technologies supporting this process operation are cranes and the devices necessary to attach, measure, and articulate the lifted weight. Different gripping and clamping mechanisms readily available in the marketplace provide the means to connect cranes to work. Cranes equipped with dynamometers commonly provide feedback on weight, while less sophisticated devices enable surfaces and edges to be joined. Among these devices are a wide variety of welding clips, jacks, clamps, and the like which temporarily hold major features and ship components together prior to final joining.

MANUFACTURING STRATEGIES:

The ability to lift and set larger units reduces the need for additional welding across structural blocks

during erection. Unfortunately, this approach requires larger, more expensive, high capacity cranes. The feasibility and capital cost may present obstacles to the shipbuilder. As a result, the process of setting blocks relies heavily on planning and engineering to maximize the limits of size and weight during final assembly and erection. Managing the information and analyzing the demand on resources (e.g., cranes) are critical steps in the overall ship construction strategy.

Fixturing

INTRODUCTION:

Fixturing is a vital process in the overall ship manufacturing and assembly operations. This process frequently relies on complex production aides to restrain, clamp, and manipulate production parts during specific manufacturing operations. To maintain data points which control dimensional accuracy, a combination of hard and soft production fixtures are usually employed. Because low volume, batch manufacturing has forced shipyards to rely on less sophisticated fixtures, tolerances of finished products are rather inexact compared to other industrial products.

STATE OF THE INDUSTRY:

Shipbuilding typically uses fixtures throughout the manufacturing and assembly operations. For machining operations, certain processes such as surface milling and shaft turning demand special blocking and indexing. For these work centers, accuracy and repeatability are critical in achieving design specifications that often refer to surfacing conditions and flatness/straightness tolerances made possible only with precise machine tools. For other non-machining operations (e.g., structural steel assembly), accuracy is often sacrificed using rather simple, temporary fixtures to aid the production worker. In these instances, little effort is spent on designing and verifying the qualifications for a particular fixture.

As shipbuilders became more automated, the need for flexible manufacturing fixtures became more apparent. The ability to adapt production fixturing to low volume part fabrication and assembly challenged traditional concepts. The introduction of robotic arc welding as a production technology had several significant effects on how shipbuilding would fixture parts for assembly. Prevalent in pipe and steel assembly shop manufacturing is the use of automated manipulators capable of synchronized motion control and featuring dual rotating tables that accommodate a wide array of flexible holding fixtures. By adapting machining practices, steel assembly can clamp and hold individual parts with the same precision. The complexity and cost for fixturing depends on the critical features of a particular part design and requirements for one or more manufacturing steps. For assembly, fixturing is generally uncomplicated. Minimizing tooling requirements and set-up times while achieving favorable working positions are key to good fixturing, particularly when the parts are 200- to 300-ton assemblies (Figure 2-5).

STATE OF THE ART:

For this area, further evaluation and collaboration is underway.

STATE OF RELATED INDUSTRY:

For this area, further evaluation and collaboration is underway.

ENABLING TECHNOLOGIES:

Fixture designs have traditionally been developed by production personnel responsible for producing a part or assembly. CAD/CAM with precise design data enhances fixture design development. The ability to fit the fixture design to the final part features and the constraints of known production equipment significantly improves the quality and accuracy of the final product. By exercising the product design model, shipyards can also ascertain size, weight, and cost for proposed fixtures while simultaneously developing the best construction strategy.

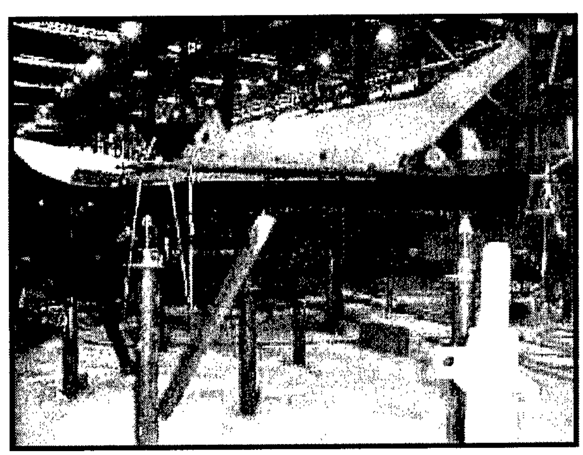

Figure 2-5. Fixed Pin Jigs

MANUFACTURING STRATEGIES:

DFMA embodies the philosophy of producing parts or assemblies with an economy of production. Fixturing relies on the necessity to control the position and orientation of production parts or assemblies for certain operations. The results of which reduce labor costs (e.g., welding out-of-position) while maintaining dimensional control of the finished product. This necessity alone is enough to maintain a fixturing program that identifies, designs, maintains, and reconstitutes fixtures for current and future production.

Positioning

INTRODUCTION:

Positioning, as a production process in shipbuilding, almost universally refers to those methods involved in moving and orienting larger material items to perform a primary or secondary operation. The process typically involves loading/unloading work-in-process, and accurately positioning dimensional planes, features, or objects relative to a particular manufacturing or assembly work center. Positioning also embraces the methods and practices used to install components or large-scale, multi-ton objects (e.g., outfitted platforms) by manipulating the volume of required space to fit the volume of available space.

STATE OF THE INDUSTRY:

The shipbuilding industry utilizes a number of different methods to position and orient work pieces as part of the manufacturing and assembly operations. Besides the use of various style cranes, shipbuilders often rely on various devices to establish coordinate and spatial positioning. These devices include self-propelled, multi-axis manipulators; indexing tables; multi-ton rollers; jack-and-skid devices; power conveyors; skid blocks; hydraulic jacks; and welding clips. Used in combination, these items can achieve the desired position of condition relative to any fixed point, regardless of features that may make such orientation otherwise impossible.

STATE OF THE ART:

For this area, further evaluation and collaboration is underway.

STATE OF RELATED INDUSTRY:

For this area, further evaluation and collaboration is underway.

ENABLING TECHNOLOGIES:

The ability to move and position ship components relies on a variety of conventional mechanical, pneumatic, and hydraulic support equipment. Many of these applications are uniquely specialized and reflect the development of a special need based on a specific manufacturing or assembly task. Because shipbuilding involves relatively large components, there is widespread innovation in developing or modifying off-the-shelf products to meet particular needs. As a result, the range of suppliers is as diversified as the applications. Sensor technologies coupled to computer programs that provide operator feedback have begun to play a key role in this process. Establishing accurate positioning to within ± 1 mm for operations such as cutting and milling is as important to manufacturing as maintaining the same tolerance in assembly. Likewise, detecting the relative position of a surface, plane, or point is as critical as being able to position that object.

MANUFACTURING STRATEGIES:

The ability to accurately position an object relies not only on the devices responsible for manipulating that object in space, but also those manufacturing processes that contribute toward its physical features. While the range of products that enable shipbuilders to position material and components is diverse, the primary objective is to execute the process efficiently and cost effectively with some standard array of techniques and procedures. Like other support processes, positioning large objects poses challenges to the safety of personnel. As a result, diligence in planning and executing complex positioning of large, heavy objects is crucial to the overall process.

Grinding and Sanding

INTRODUCTION:

Grinding and sanding are similar processes which are prevalent throughout the manufacturing and assembly operations in the shipbuilding industry. Typically performed with portable or stationary powered equipment, they are considered to be secondary processes because they remove material as part of a cleaning or preparatory step (e.g., deburring; removing weld spatter, paint, or paint primer). As a finishing or surfacing process, grinding refers to a more aggressive operation in which larger amounts of material are removed. In cases of precision grinding, numerical control machinery is used to produce fine finishes and/or close tolerances.

STATE OF THE INDUSTRY:

Since the same tools and abrasives can be used for grinding and sanding, the difference is more a matter of degree than a strict definition of terms. Both operations use an abrasive material applied under power. Grinding involves removal of material and is most commonly used: (1) to deburr (or dress) rough edges of mating surfaces prior to welding and (2) to blend or fair adjoining surfaces after welding. The execution of this operation leaves the final results in the hands of the mechanic. Most free-hand operations in a shipyard allow for the use of coarse grits. The production item being ground is either held to the grinding media or the media is held to the work. Here, no single combination of grit and bonding agent is effective for all materials or all conditions. The most popular used grit is aluminum oxide. However, zirconium oxide has proven to have a longer cutting life and a higher cutting speed on steel. The abrasive media used depends on the type of work and desired finish, which dictates the appropriate grit (or coarseness) and cutting speed. For grinding, the abrasive media and bonding agent are formed into a disk that is turned at high speeds by a pneumatic or electric hand grinder.

For sanding, the abrasive is bonded to a paper or cloth, and is turned by a pneumatic or electric-powered hand tool in either a disk or belt form. Sanding is a generally a surface preparation operation where paint or rust are removed to prepare for welding or repainting. A larger variety of grit (or coarseness) is available depending on the final finish.

STATE OF THE ART:

Grinding and sanding are used for final edge preparation during welding and ship construction. Typical grinders used by shipbuilders are pneumatic/ electric and hand held, because most older grinders are heavy and not ergonomically designed. State-of-the-art grinders are lighter, quieter, and designed for maximum operator comfort. Pneumatic grinders are also more efficient, and use less compressed air volume. Grinding and sanding consumables have increased their effectiveness by incorporating characteristics such as self-cleaning and longer-lasting materials.

STATE OF RELATED INDUSTRY:

The state of related industry is the same as the state of the art in grinding and sanding.

ENABLING TECHNOLOGIES:

To grind or sand a surface regardless of its base metal or product type (e.g., steel plate, pipe spool, sheet metal) usually requires hand held, portable machines. These tools can accommodate various grinding or sanding wheel sizes and shapes depending on the application. To improve ergonomics and reduce operator fatigue, grinding tools are available in three configurations: straight, angle, and surface. For specific applications, there is also a range of power sizes varying between one-third and six hp, making even the most challenging job relatively easy. Compressed air and electricity are the usual sources of power for these tools. However even in the most rigorous conditions, it is still important to consider the hazards of using electrical hand tools. Shipbuilding is no exception, particularly when access to small spaces offers difficult evacuation in the event of a fire. The most popular tool suppliers include Atlas Copco, Ingersol Rand, ATSCO, and Milwaukee.

MANUFACTURING STRATEGIES:

Because grinding and sanding processes occur over a wide range of applications and in different environments, there is no discernable strategy. Generally, the objective is to sustain consistency in the sourcing and use of abrasive materials for these processes.

Washing and Cleaning

INTRODUCTION:

Washing and cleaning involves the use of mild or aggressive chemical agents to achieve acceptable surface conditions as a prerequisite for another process operation. These production processes are used to eliminate rust, scale, oxidation, flux, grease, dust, and/or other foreign particulates. Cleaning certain material types also secures a level of preservation consistent with expected life cycle requirements.

STATE OF THE INDUSTRY:

Stainless steel and copper nickel are typical material types used in shipbuilding piping systems. Both high-pressure and low-pressure piping systems must meet certain criteria to perform satisfactorily. Other production materials requiring preservation coatings also need to be cleaned to ensure the durability and integrity of the system over its operating life.

While cleaning remains somewhat unchanged technically, the use of more aggressive agents and preservatives has changed. Rough hand cleaning can

be achieved using several common agents such as varsol, acetone, or intex. Neutral cleaning agents like hot water are also used to remove lubricating greases common to production operations. More aggressive agents (e.g., sulfuric acid, caustic soda, trisodium phosphate) are typically applied in dip tanks designed specifically for the size and type of material. Tank sizes range six and ten feet in width, 20 to 30 feet in length, and five feet in depth. Immersion (or soak) times and temperatures are controlled to satisfy desired cleanliness, but must be closely monitored. Statistical process control charts are among the tools that aide in this process. Timers and devices for immersing materials into chemical cleaning tanks are relatively unsophisticated, but often effective. General maintenance of such tanks, normally semi-annually, involves routine flushing and replenishment of the cleaning agents.

STATE OF THE ART:

Cleaning processes and systems are constantly being improved and optimized to meet the demands of a wide variety of precision cleaning requirements. High pressure, ultra-high pressure, and immersion systems have become more automated and customized to meet specific size constraints, material compatibility issues, throughput requirements, and other needs specific to a cleaning application. High-pressure cabinet washers are typically used to clean parts with simple to medium geometries. Cabinet washers are advantageous for line-of-sight cleaning of parts contaminated with greases and oils by using aqueous chemistries. Ultra-high pressure cleaning systems use pressures in the 15,000+ psi range for very aggressive cleaning and coatings removal. Immersion cleaning is another process that effectively cleans parts with complex geometries. Bath agitation techniques such as spray-under immersion or ultrasonics can also enhance the cleaning effectiveness.

STATE OF RELATED INDUSTRY:

Many cleaning applications are turning to more environmentally friendly chemicals and processes as alternatives to traditional solvent cleaning. The use of pressurized water with an environmentally benign chemistry has been effective in cleaning metal parts of all shapes and sizes. The cleaning systems are customized and scaled-up or down to fit any size part and accommodate throughput and fixturing requirements. Another type of cleaning which can remove grease, scale, oils, and oxidation is carbon dioxide pellets. This method is environmentally friendly and does not create an additional wastestream.

ENABLING TECHNOLOGIES:

After completing a washing or cleaning process, organizations can employ various techniques to inspect the effectiveness of the process. Part of the final inspection after cleaning is visual. For situations that require more robust scrutiny, bore scopes can be used to ensure the integrity and consistency of the finished process. To maintain the cleanliness of fabricated pipe and pipe assemblies prior to actual installation, organizations also use several methods to protect the internal surfaces. The use of polyvinyl pipe caps, which act as corks to seal the opposing ends of a pipe detail, works extremely well. Additionally, efforts to seal these caps with tape or fasteners is common when ensuring cleanliness over a longer duration. Another alternative is the use of rigorous blanks fashioned from sheet metal.

MANUFACTURING STRATEGIES:

Perhaps the only discernible strategy readily apparent within the shipbuilding industry is the desire to maintain process zones for similar cleaning agents and cleaning practices. Additionally, the ability to kit or palletize similar production materials for downstream use quantifies the demand on washing/ cleaning capacity.

Milling

INTRODUCTION:

Milling is a primary operation in shipbuilding that provides surfacing, facing, and edge preparation of various close tolerance piece parts. The process is associated with the fabrication or manufacture of finished piece parts requiring intricate accuracy obtainable only with computerized numerical control machines. As a machining operation, milling machines are capable of performing gouging or cutting in two axes of motion simultaneously. Consumable cutting tips and rotary cutters operate in a dry or self-lubricated system to remove material at fairly high rates in a series of programmed trajectories across the work piece.

STATE OF THE INDUSTRY:

Milling is usually associated with machine shops where materials are manipulated in a series of operations to produce highly accurate piece parts. Milling is also exceedingly important to welding

operations in shipbuilding. The ability to produce beveled edges on structural plating before they are joined by welding processes reduces fit-up and welding times. In addition, automated and mechanized welding processes for joint designs use less weld volume than typical thermal cut joints. These processes have proven to be exceeding efficient and cost effective in eliminating the required amount of time needed to clean and weld joints.

As a machining operation, milling utilizes abrasive cutters which rotate at variable speeds to cut or remove material along a programmed path (Figure 2-6). Available in different sizes, cutters are generally fabricated from high strength steel which improves performance capability. Heat produced by the cutting process is usually cooled by lubricants, although there are instances where dry cutting can be used depending on the material grade and thickness. For welding, milling steel plated edges includes square butt joints; single-V butt joints (45° and 60° included angles); double-V butt joints (60° included angle); and double-U butt joints (36° included angle). Material types which are milled at depths up to two and 5/16 inches (e.g., carbon steel; high tensile strength steel; HY steel; high strength low alloy steel) require different feed and cutting speed rates.

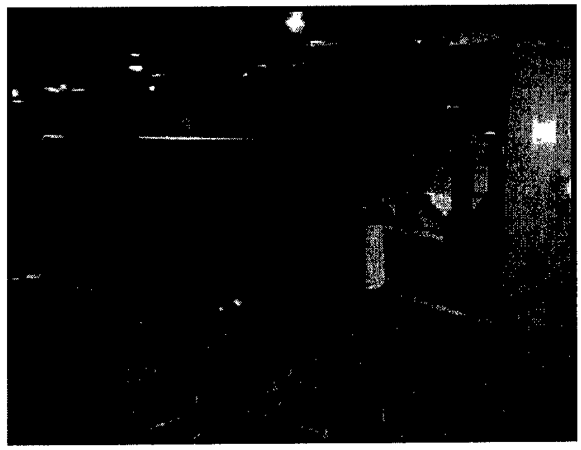

Figure 2-6. Milling Machine

STATE OF THE ART:

CNC milling centers are considered state of the art, and can increase cuttings speeds and feed rates. Characteristics of these new machines include: through spindle coolant, high speed spindles, controllable acceleration/deceleration rates, and rapid tool changing. The latest insert tooling continues to provide significant increases in material removal. The programming of CNC milling centers also enables complex shapes to be fabricated. However, a significant capital investment is required to purchase machines which meet the physical requirements of the shipyard environment.

STATE OF RELATED INDUSTRY:

The state of related industries is the same as the state of the art in milling.

ENABLING TECHNOLOGIES:

Several proven technologies are involved in milling. These technologies center on process controls and cutter designs. Newer milling machines feature interactive controls where displays allow the operator to pre-select commands from a library of technical menus and data. Video displays alert operators to any abnormal occurrence in the actual operation. Cutters previously developed for standard machining have also been refined for this process operation. The design, configuration, and arrangement of these cutters is critical to the cost and operational efficiency of milling.

Recently, nanograin materials (e.g., titanium-aluminum-nitride) have been developed for coating cutting tools used to machine and mill materials like titanium. By processing and applying nanophase powders to cutting tools, tool life can be increased two-fold. This method reduces fabrication costs by increasing tool longevity, thereby reducing the number of tool changes and improving adherence to manufacturing tolerances.

MANUFACTURING STRATEGIES:

As a machining operation, milling does not subscribe to any one manufacturing process. It does, however, suggest that the execution of work performed on one or more milling machines must be planned at a level of detail that best describes work content. Determining the duration of cycle and idle times is critical to planning work for CFM.

Bending

INTRODUCTION:

Bending, as a production process in shipbuilding, almost universally refers to the manufacture of pipe piece parts. The process typically involves loading and unloading stock lengths of pipe into hydraulically assisted CNC bending machines that are capable of bending various wall thicknesses, material types, and diameters. Depending on the level of production,

the entire process can be automated. Bending also refers to sheet metal piece parts that are bent on press brake machines capable of creating a desired angle or bend. Modern sheet-metal fabrication also features CNC press brakes; however, manual machines are more prevalent in the U.S. shipbuilding industry.

STATE OF THE INDUSTRY:

Pipe bending is one of the critical manufacturing steps in pipe fabrication. The ability to execute multiple bends (known as 1-D, 2-D, 3-D, 4-D, and 5-D bends) with great accuracy effectively drives the cost of this shipbuilding operation. Bending machines are grouped according to the pipe diameters which they can process. For example, a four-inch machine can bend material from two to four inches in diameter with varying wall thicknesses. Whether mechanically operated, air/hydraulic, electric, or a combination, each machine can handle a range of different material diameters and wall thicknesses, also referred to as schedule. Ranging from 14 inches O.D. material with a 0.250 wall thickness down to 0.5 inch O.D. material typifies the scope of material processed for shipboard piping systems.

Induction bending features locally applied heat used to control individual bends rather than the cold-bending process. Depending on the material type (e.g., copper, carbon steel, copper-nickel), small diameter pipes from 0.25 inch to one inch O.D. for certain low-pressure systems are generally hand bent when installed shipboard. Bending small diameter pipes on a CNC machine provides a level of accuracy impossible to achieve with manual hand bending tools, but it also requires that such piping be fully detailed in design. The required level of effort may not warrant this engineering cost.

STATE OF THE ART:

For this area, further evaluation and collaboration is underway.

STATE OF RELATED INDUSTRY:

For this area, further evaluation and collaboration is underway.

ENABLING TECHNOLOGIES:

The ability to quickly and efficiently bend pipe spools into different configurations is important to the overall cost of manufacturing pipe. Maximizing the fabrication of bent pipe details eliminates the need to introduce fittings as well as the associated welding process that accompanies naturally occurring joints. So as a manufacturing process, bending is preferred.

Major equipment suppliers of DNC/CNC pipe bending machines include Swartz Weirtz and Pines. A number of press brake machines are also available through Pullmax and others that provide CNC control bending for sheet metal.

MANUFACTURING STRATEGIES:

For the shipbuilding community, bending operations occur shipboard as well as in the supporting manufacturing shops. As a result, the principle strategy for these production operations is aimed at establishing work content that is compatible with available production capacity and arranging those resources accordingly. This principle loosely defines CFM and lean manufacturing, and hinges around the establishment of manufacturing cells that offer high capacity with flexibility. Rather than cluster similar operations in specific areas, the arrangement of the equipment should be dictated by the work content and the operations needed to produce a family of parts. This approach would maximize production capacity.

Winding

INTRODUCTION:

Winding refers to the repair of electrical motors that require periodic maintenance as part of a comprehensive ship overhaul. Winding, also known as rewinding, involves both AC and DC motors of various sizes. The process typically entails cleaning armatures and stators; using solvent baths; coating or varnishing armatures; and conducting visual inspections to maintain the integrity of electrical motors.

STATE OF THE INDUSTRY:

Shipbuilding, particularly ship repair, places certain demands on the capabilities of select production processes. One rather critical but low volume process is rewinding electric motors. Motor repair involves the removal and disassembly of electrical motors to identify specific problems. At the heart of an electric motor is the stator, a series of copper wires wound around a central cylinder. The rotor revolves around the stator, and together they create the polarity for generating electricity. Inspecting and cleaning the stator is critical for extending the life of a motor. To accomplish this, the rotor and stator are washed, then baked to establish a clean and dry condition. Ensuring that the copper windings are clean is vital for the next step, varnishing, in which the stator is dipped into a bath of the preservative to impede

oxidation. Visual inspection and testing are also part of the process.

STATE OF THE ART:

For this area, further evaluation and collaboration is underway.

STATE OF RELATED INDUSTRY:

For this area, further evaluation and collaboration is underway.

ENABLING TECHNOLOGIES:

Because winding is a limited production process, no need currently exists for investing in technology to improve overall efficiency.

MANUFACTURING STRATEGIES:

The demand to maintain an in-house winding process is limited even for the repair and overhaul shipyards. Alternatives such as outsourcing this process are more advantageous, since a strong business case cannot generally be made. As a result, no applicable manufacturing strategy exists.

Cable Pulling

INTRODUCTION:

Pulling (or installing) electrical cables that support shipboard services involves a majority of manual processes that have changed little over time. Routing the wide range of electrical cable sizes that make up the ship's power, communications, and generation services can typically involve miles of cabling. A majority of the electrical services for military combatants includes large diameter, high voltage shielded cabling that runs hundreds of feet between connection points. Recent practices have introduced fiber optic cabling for low voltage communications systems.

STATE OF THE INDUSTRY:

Cable has traditionally remained unchanged. The majority of ship service cabling involves armored cable that runs from source to service. Nearly 100% of a ship's cabling is manually coiled, hung, pulled, and stretched. Almost all cable is suspended in overhead areas of the ship, which requires the installer to lay in a prone position in order to snake the cable from one point to another. For lengths that exceed 400 to 500 inches, the challenge often exceeds the human physical limit, thereby resulting in a higher-than-average number of worker's compensation cases. Specialized hand tools and techniques aid in cable installation, and most often are the products of experience and knowledge. To complete the process of installing cable, different commercially available cutting and crimping tools are used. Portable cable pulling machines facilitate routing cables where space and routing paths are reasonably unencumbered. Other practices such as pre-cut cable lengths derived from 3-D product models enable installers to handle only the length required, thereby eliminating the labor cost to cut and the material cost to discard excess cable.

STATE OF THE ART:

For this area, further evaluation and collaboration is underway.

STATE OF RELATED INDUSTRY:

For this area, further evaluation and collaboration is underway.

ENABLING TECHNOLOGY:

For commercial applications where general service cable is installed, pneumatic or electrically powered cable pulling machines are used. Operation of these machines depends largely on available space and the ability to position the machine strategically. Commercially available, the machines essentially push the cable as it is manually routed by hand along its pathway. As the cabling is run, additional cable pulling machines grasp and pull the cable so that the next leg can be routed for the subsequent run. The added mechanical advantage enables larger diameter cabling to be installed efficiently, while reducing the incident rate of worker's compensation cases. Because there is concern regarding possible damage to costly ship cabling, the powered cable pulling machines are generally not used for military combatants.

MANUFACTURING STRATEGIES:

A rigorous sequence plan is a necessity for installing many of the components that comprise a ship's distribution system. Placing available resources and material within ship spaces to promote an orderly execution of work puts inordinate responsibility on the planning function. However, the ability and desire to maintain a fully integrated schedule is driven by demand. Minimizing the amount of labor spent on non-value added activities is the keystone of what many shipyards are now calling CFM and JIT manufacturing.

Hydrostatic Testing

INTRODUCTION:

Hydrostatic testing (or hydro-testing) involves pressurizing specific ship components or systems to determine and validate their structural integrity. Most piping systems on ships are hydrostatically tested to 1.5 times their operating pressure before they are placed into service. Testing involves isolating a component from adjacent ship systems (e.g., tank or piping system); connecting and applying air or water pressure; and identifying potential leaks using leak detection devices. The process is iterative until the complete system achieves the required integrity. Testing guarantees system integrity and, ultimately, the crew's and ship's safety.

STATE OF THE INDUSTRY:

Hydrostatic testing begins during the design development stage, when ship systems are diagrammed into schematic drawings that identify specific boundaries for testing. These boundaries establish critical dimensions of each piping system that will enable testing under shop or ship conditions. Ideally, hydrostatic testing of all piping under a shop condition would reduce costs; however, this is not feasible. Piping systems must ultimately be tested as one continuous system which can only be accomplished shipboard.

STATE OF THE ART:

The state of the art in hydrostatic testing is essentially the same as the state of the industry. Sophisticated CAD models and finite element model analyses of the piping systems can be conducted to help identify whether or not design requirements for the system are met. These analyses can assist in guiding instrumentation decisions (e.g., strain gages, displacement transducers) and location during hydrostatic testing, if the integrity of the piping system design is in question. While these modeling techniques can be employed to assist in determining the integrity of these systems, there is no substitute for hydrostatic testing to ensure the health and safety of personnel working on and around pressurized ship systems.

STATE OF RELATED INDUSTRY:

The state of related industry in hydrostatic testing is essentially the same as the state of the industry.

ENABLING TECHNOLOGIES:

As a practice, the process of performing hydrostatic testing remains unsophisticated. After all non-destructive testing (e.g., visual, dye penetrant) is completed, hydrostatic testing can usually begin. Testing entails the use of blanks that create an endpoint of the pressurized boundary, which typically occurs at a fitting or valve. A hydro pump is used to pressurize the fluid and hold the pressure within the allowable range during the visual inspection. Calibrated relief valves are used to protect the system from inadvertent over-pressurization.

Air or water is then pumped into that section of the piping system to a pre-determined pressure, normally 1.5 times the design system pressure and monitored between five and 30 minutes using a gauge. Permanent deformation of a component or leakage through a brazed, soldered, swaged, or welded joint is unacceptable. These discrepancies must be repaired, and the item is retested at full hydrostatic pressure to prove the integrity of the repair. Mechanical joint leakage (e.g., O-rings, flange gaskets) is not a cause for test failure. These joints can be repaired after the hydrostatic test and be proven tight with a test at normal system operating pressure.

As ship piping systems evolve and extend into a larger number of ship spaces, incremental testing is performed. Final hydrostatic testing is mandatory to guarantee the integrity of the entire piping system. To accomplish this process, a low pressure air test is performed to assure that nothing has been left open and all the valves are positioned correctly. After the low pressure test has been satisfactorily completed and all problems corrected, final system hydrostatic testing is initiated. Until all discrepancies are identified and corrected, hydrostatic testing continues as an iterative process. Hydrostatic testing is the second step in a progressive test program. The system is inspected to ensure that it is complete and built in accordance with the applicable drawings and directives. After hydrostatic testing, the system is flushed to establish the required system cleanliness. Operational testing is then performed to prove that the system operates as designed. The final testing before sea trials is a demonstration that all of the individual systems will work together to support the total operation of the ship. An extensive sea trial is then conducted to demonstrate that the ship will perform as designed. In addition to hydrostatic testing, certain pipe systems can require flushing, a drop test, and/or an operational test as well as a turn-over inspection.

MANUFACTURING STRATEGIES:

Ensuring the health and safety of personnel working on and around pressurized ship systems is key to any manufacturing approach. During the assembly of piping systems, size and complexity require that certain safeguards are in place to facilitate testing. Inaccessibility to critical weld joints that join pipe fittings on large, thick-wall high pressure systems demands that hydrostatic testing must be performed systematically. To accomplish this task, accurate records which document test completion results must be maintained throughout the ship's construction schedule and process. Also exceedingly important is the use of a highly visible tagging system that alerts the workforce to the status of either tested or potentially dangerous conditions.

POINTS OF CONTACT:

For further information on SP-16 Panel items in this report, please contact:

Mr. Joseph Bart Sickles
Concurrent Technologies Corporation
(814) 269-6444
sickles@ctc.com

Mr. Allan G. Roy
Newport News Shipbuilding
(757) 380-2117
roy_ag@nns.com

Section 3

Welding Technologies (SP-7 Panel)

CHAPTER SUMMARY

Technological developments in ship construction and welding have been intrinsically linked throughout the century. In many cases, it is difficult to identify whether a welding development enabled a new ship design or whether an innovative ship technology was the driving force for a welding development.

Welding developments in the shipbuilding industry have been accelerated by various events, most notably the two World Wars. During World War I, the newly evolving electric arc welding processes were proven to be essential tools that supported the war effort, especially in the construction of ships and other steel structures. As a result, the American Welding Society under the leadership of the War Department was established immediately following the end of the war. Likewise, World War II placed new demands on the welding industry to develop new processes and materials so large numbers of ships could be produced annually under a compressed construction schedule. Among the technologies that gained impetus for rapid development from the war effort were reduced hydrogen electrodes and submerged arc welding.

As with most technologies, the rate of innovation and advancement in welding has accelerated in recent years. Again, the shipbuilding industry's needs have been a major driving force in these developments. Modern ship designs are continuing to incorporate new materials which, in turn, require comparable new welding materials. Global competition in ship construction has also demanded more productive and efficient automated systems. Although U.S. shipyards have not incorporated the same level of robotics and automated systems as their international counterparts, the United States has been and continues to be the leader in implementing advanced welding materials. This effort has primarily occurred because of the stringent requirements of the U.S. shipbuilding defense industry.

Beveling

INTRODUCTION:

Beveling is a process that prepares material surfaces (e.g., plate edges that form a joint) for welding to ensure a quality full penetration weld or, in some cases, the correct depth of penetration. In addition, this angular edge preparation permits greater access to the root of the joint and easier manipulation of the welding torch. Beveling is achieved for block assembly, erection beams, and other subsequent welding practices through milling, grinding, and cutting machines.

STATE OF THE INDUSTRY:

In shipbuilding, beveling occurs at various stages in the first operations as well as subsequent and final assemblies. These processes can be applied in a shop, shipyard, or on-board environment. Historically in first operations, plate edges are beveled during the flame cutting processes. With the advent of plasma cutting, many of these systems could not provide the necessary bevel, so a secondary operation was added to the production line. Recently, improved torch holding fixture designs; advanced plasma cutting torch designs; and better control software have been incorporated into modern plasma cutting systems. As a result, plasma cutting tables can now produce beveled edges in a single cutting operation.

For many U.S. shipyards, the legacy CAD designs do not include beveling commands in the machine operational codes. Although the technology is available, many refrain from implementing the practice due to re-engineering requirements. Shipyards which have recently re-capitalized and re-engineered their design efforts are using the bevel capabilities of plasma cutting processes during some first operations. Most of these are foreign shipyards; however, Avondale Shipbuilding, Newport News Shipbuilding, Ingalls Shipbuilding, and the Alabama Shipyards have incorporated robotic plasma beveling into their beam-cutting first operations shops.

Laser beam cutting is emerging as a process for first operations joint preparation. Vosper Thorneycroft (UK) routinely uses laser cutting for initial plate preparation. Bender Shipbuilding is implementing a six-kW cutting system at its Mobile, Alabama facility. Although the latter situation is targeted for commercial shipbuilding applications, the system is only being applied to a limited number of ship and weld joint designs which capitalize on cutting technology.

Currently, neat-cut processing and accuracy control in the shipyards have not progressed to the point

where all cutting and beveling can be performed during first operations. Bevels for subsequent and final assemblies are still achieved through manual cutting and grinding on-board ship. In addition, many welds must be back-gouged to provide a bevel on the second side of the weld joint. Back-gouging is similar to either carbon arc-gouging or oxy-fuel cutting torches typically used to prepare the backside of a weld. Some subsequent grinding may also be required. For aluminum and other non-ferrous materials, mechanical milling tools or plasma torches are used.

STATE OF THE ART:

The state of the art is the same as the state of the related industry.

STATE OF RELATED INDUSTRY:

Like shipbuilders, heavy equipment manufacturers (e.g., Caterpillar, JI Case, Deere & Company) routinely apply CNC plasma and laser beam cutting for first operations processing of similar steel alloys and thicknesses. The key driver is the extensive use of automation in their manufacturing operations. The accuracy of plasma and laser beam cutting, combined with the accuracy control of other processing and incoming material, provide the precision and repeatability necessary for robotic welding without feedback control. Most of these manufacturers' assemblies are smaller than the typical ship block. Fabricators in the construction industry largely employ the same practices and techniques for beveling as do the shipbuilders for final assembly.

ENABLING TECHNOLOGIES:

CNC and robotic systems for first operations beveling are well established technologies, although not widely implemented in U.S. shipbuilding. However, portable processing equipment is currently not available for producing weld preparations of plate and erection beams on-board ship.

MANUFACTURING STRATEGIES:

Ideally, all cutting and beveling should be performed in first operations with all components neat-cut for initial and final assemblies. But until the accuracy control of subsequent processing and incoming material advance to that point, the need for technologies to trim and bevel assemblies in the shipyard will still exist. To enhance U.S. competitiveness, manufacturing strategies need to address the arduous portions of the process flow, specifically the time-consuming, skill-dependent manual operations and the delays caused by the difficulties of preparing final assembly joints during the final assembly operations and outfitting.

Fitting

INTRODUCTION:

Fitting is the alignment and placement of parts to be welded. This process is one of the most important operations for cost effective welding. The overall dimensional accuracy of ship structures is directly related to the accuracy and adequacy with which parts are aligned prior to welding and held in position during the welding operation.

For the most part, fitting tools and methods are consistent across the steel working industries. In some cases, special design tools and devices have found uses at individual facilities. However, the basic methods of plate alignment, tack welding, and in-process support of the pieces to be welded have not significantly changed over the years.

STATE OF THE INDUSTRY:

The shipbuilding industry uses most of the same fitting devices and techniques as those of similar industries. The size of ship structures, however, may limit the adequacy of those fitting devices and techniques. For example, the stackup tolerances can be significant when one considers the combined effect of minor fit-up irregularities on the overall dimensions of the finished vessel. Additionally, the sheer size of the ship structures requires many subassemblies or blocks. Then the major concern is the fitting of individual blocks together, each with multiple weld joints that must be aligned at erection joints. Consequently, minor fit-up variations in the subassembly stage can result in major fabrication challenges as each subsequent manufacturing step occurs.

On panel lines, many U.S. shipbuilders employ mechanized devices for aligning plates for one-side welding of butt joints and the placement of stiffeners on those panels. In most cases, the parts are tack welded in place to hold the alignment during the welding operation. For erection joints, the parts are held in place with strongbacks (a temporarily attached structural member that straddles the weld joint) to maintain the proper alignment for welding. The strongbacks are usually attached to the structural members using fillet welds but, in some cases, specially designed strongbacks are mechanically fastened to

short tee-headed studs which are arc stud welded to the members to be aligned.

The importance of fit-up on the fabrication efficiency and overall dimensional accuracy of a vessel is well established. Significant effort is being put forth to develop manufacturing techniques to minimize or eliminate the need for fit-up aids. Currently, the subsequent removal and cleanup of anchoring devices result in blemishes on the surface of the finished components. More information on this technology can be found in the Study of Fitting and Fairing Aids of U.S. Shipyards: NSRP Report #0195.

STATE OF THE ART:

Given the constraints of the shipbuilding industry and the types of components being fabricated, the state-of-the-art fitting techniques and devices being used are as sophisticated and effective as those of other industries. One technique applicable to shipbuilding is the use of a specially designed tab-and-slot configuration for assembling T-joints. Ideally fabricated with laser beam cutting, the design of the tab is such that it can provide an interlock, once inserted through the slot and twisted. This design results in self-fixturing and creates an effective positioning for welding. Some heavy equipment applications have achieved good results with this method.

STATE OF RELATED INDUSTRY:

The shipbuilding industry is at least as advanced as other related industries in the area of fitting for welding.

ENABLING TECHNOLOGIES:

Enabling technologies would include any method which improves first operations and subassembly accuracy, resulting in erection joints that fit more easily. If improved first operations could not alleviate all fit-up issues, then equipment which can align beams and plates during erection would also be necessary. Such equipment must be portable, accurate, simple to operate, provide easy accessibility to the weld joint, and be secured to the work piece in such a manner that tear-down and cleanup is minimized.

MANUFACTURING STRATEGIES:

Manufacturing strategies would include any method which improves the accuracy control during the initial stages of fabrication. Another approach would be to design components that can be fitted using the tab-and-slot configuration technology.

Shielded Metal Arc Welding

INTRODUCTION:

Shielded metal arc welding (SMAW) is a process that produces coalescence of metals by heating them with an arc between a covered metal electrode and the work pieces, and obtains shielding from the decomposition of the electrode covering. As the electrode melts to form the weld, the coating decomposes into a gaseous atmosphere to shield the weld from contamination while molten, and then forms a slag to protect the weld as it solidifies and cools. Although it is one of the oldest arc welding operations, this process is also one of most durable for structural and pipe applications.

The shipbuilding industry has been a leader in the use of SMAW. Many advancements in new welding electrodes have been implemented because of SMAW's multi-applicability to high strength steels and the climatic environmental challenges common to shipyards. The shipbuilding industry is implementing high yield structural steel covered electrodes which have higher toughness and more cracking resistance. SMAW is the preferred process for shorter welds and tack welding because of its quick setup and wide choice of electrodes.

STATE OF THE INDUSTRY:

Before the advent of welding automation and robotics, foreign shipyards often employed a variation of SMAW referred to as gravity welding. In this process, a long covered electrode is inserted in a specially designed electrode holder which enables the electrode to feed itself along a weld joint, once the arc is initiated to produce a fillet weld. Gravity welding permits a single operator to run multiple units simultaneously. This technique has seen limited use in U.S. shipyards, mainly because mechanized processes such as flux cored arc welding are being used instead.

Although efforts are being made to replace it with more productive welding processes where appropriate, SMAW is still widespread throughout the shipbuilding industry. The process is particularly extensive for tacking and pipe welding applications. SMAW requires little physical equipment at the welding location, making it the process of choice for those applications where access is limited.

STATE OF THE ART:

The state of the art of SMAW is essentially the same as it was in 1990. One improvement has been in the

area of electrode coatings for low hydrogen electrodes. Versions of these electrodes now exist in which the coating is formulated with components that are less hygroscopic, meaning that they are less susceptible to moisture pickup when exposed to the atmosphere. Referred to as moisture resistant versions, these electrodes are capable of maintaining their low moisture content for longer periods of time without storage in a heated electrode oven. With the advent of moisture resistance versions, low hydrogen electrodes are now purchased according to a prescribed moisture content. Designated as -H4, -H8 or -H16 types, the number indicates the expected maximum amount of diffusible hydrogen in terms of $mm^3/100g$.

STATE OF RELATED INDUSTRY:

The use of SMAW by related industry is quite similar to those of the shipbuilding industry. In fact, many industries have benefitted from the developments related directly to ship construction and repair. Despite being displaced by more productive processes in certain applications, SMAW is extensively used in related industry. SMAW provides quick setup capabilities; works well in applications where access is limited; and offers users a wide range of electrodes including moisture resistance versions. The process is also advantageous for welding certain alloy materials when consumables are unavailable for other, more efficient welding processes.

ENABLING TECHNOLOGIES:

Enabling technologies related to SMAW is rather limited. The exception would be the continuing advancement of moisture resistant versions of low hydrogen electrodes.

MANUFACTURING STRATEGIES:

Most manufacturing strategies are aimed at replacing SMAW technology with processes that have higher productivity. However, SMAW will continue to play a role in applications where access is limited and/or small amounts of welding are necessary.

Gas Metal Arc Welding

INTRODUCTION:

Gas metal arc welding (GMAW) is a process that produces coalescence of metals by heating them with an arc between a continuous filler metal electrode and the work pieces, and obtains shielding entirely from an externally supplied gas. This process is a primary method for fabricating ship structures, and is used extensively for piping and pressure vessel components.

STATE OF THE INDUSTRY:

GMAW is very flexible, in that changes in the voltage-amperage relational curves and power supply capacity can provide quality welds in many materials. This process can perform welding in all positions, either manually or in various robotic or mechanized forms.

The joining of high yield structural steels is one example of a critical shipbuilding application that uses GMAW. Because the U.S. Navy imposes strict requirements for shock resistance; static and fatigue strengths; low temperature toughness; and low diffusible hydrogen contents, GMAW is optimal to use. The most stringent scenario for the joining of high yield structural steels is in submarine construction. General Dynamics' Electric Boat Division is one of the premier GMAW fabricators in the world. Although some applications cannot be economically applied in broader shipbuilding uses, many U.S. shipbuilders are competitively implementing GMAW for general production use.

Two-wire GMAW processes (variations on the single-wire process) are achieving higher deposition rates; reduced distortion due to lower heat inputs, and good mechanical properties to the application involved. Due to the higher travel speeds associated with these processes, they must be mechanized or used with robotics. Current applications in European shipyards involve panel lines.

STATE OF THE ART:

For critical applications, manufacturers of boiler and pressure components are very competitive with the shipbuilders in the fabrication of high strength alloys. Many of the manufacturers' developments came about from their prior experience in producing components for the nuclear U.S. Navy. These applications take advantage of recent advances in microprocessor-based power supplies. The sophisticated technology provides greater control over power output and feedback, allowing a single power supply to be used in a variety of positions, with various types of materials, and with a high level of process robustness.

STATE OF RELATED INDUSTRY:

In several countries, GMAW is the dominant welding method for structural connections for building and bridge erections. This process is also widely applied in the automotive and light manufacturing industries for thicker-section welding applications.

ENABLING TECHNOLOGIES:

To meet ongoing requirements for increased productivity, shipbuilders need to rely on continued advancements in GMAW process controls, consumables, and power supplies to improve process robustness (e.g., increase throughput, reduce inspection); increase deposition rate; and control deposition and heat input to accommodate new steel developments and design (weld size) requirements. Shipyards would also benefit from advances in emerging technologies that integrate welding engineering with other ship design and production processes, such as:

- Advances in statistical process control and numerical advancement approaches to allow the rapid development, qualification, and application of welding procedures.
- Automated storage, retrieval, and selection of welding procedures and process information.
- CAD technology which includes weld process requirements (e.g., material selection, joint design, access for welder or process automation), and accommodates weld-induced residual stress and distortion into the ship product model.
- Improvements in cutting, beveling, fitting, and accuracy control to produce accurate, repeatable joint preparations that are easier to weld by manual or automated GMAW.
- Reduction in the production of or improvements in the extraction of welding fume. In addition, emerging OSHA and EPA regulations pertaining to worker's exposure to chromium, manganese, and nickel will significantly impact the ability of shipbuilders to use these processes.

MANUFACTURING STRATEGIES:

GMAW advancements are driven by:

- Changes in steelmaking practices which require different filler metal chemistries and welding heat inputs for meeting structural requirements.
- More stringent design and product requirements for fairness and dimensional control. This advancement demands a more precise control of weld size and heat inputs.
- Increased difficulty in hiring and training qualified welders, which requires high levels of process robustness to accommodate welders of varying skill levels.
- Increased levels of mechanization and hard automation, which also require high levels of process robustness.
- Incorporation of welding into the shipbuilding enterprise. Welding process requirements and impacts must be incorporated into the electronic ship product model.

The U.S. shipbuilding industry is represented as a small percentage of the welding equipment and filler metal market. As a result, the shipbuilding industry needs to take advantage of developments driven by other industries. The ultimate choice would be to purchase welding consumables produced under commercial specifications, as this would significantly reduce material costs.

Flux Cored Arc Welding

INTRODUCTION:

Flux cored arc welding (FCAW) is a process that produces coalescence of metals by heating them with an arc between a continuous filler metal electrode and the work pieces, and obtains all or partial shielding by a flux contained within the tubular electrode. One advantage of this process is its ability to weld through pre-construction paint primers with an acceptable weld quality, making it the process of choice in many shipyards.

STATE OF THE INDUSTRY:

FCAW is a primary method for fabricating ship structures. Although most shipyards use gas-shielded electrodes, other industries (e.g., building construction) typically use materials that do not require a shielding gas. The choice depends on the material properties required for the application and the physical limitations of the workplace.

The shipbuilding industry has historically had many products created for specific applications. Among them are electrodes with fast freezing slags to facilitate all-position welding; products with low diffusible hydrogen deposits; and materials with low-temperature notch toughness. One advantage of FCAW is its ability to weld through pre-construction paint primers with an acceptable weld quality, making it the process of choice in many shipyards. Because welding manufacturers can readily modify flux compositions to adapt to emerging shipyard needs, FCAW is expected to continue playing a major role in ship fabrication.

Internationally, the recent trend for shipbuilders is to use FCAW as a replacement for either shielded metal arc welding or gas metal arc welding. Japanese shipyards that extensively use automated processes employ flux-cored electrodes because the deposition

rates and operating characteristics are especially suited to automation. Flux-cored electrodes have recently been qualified for U.S. military shipbuilding; however, they are not widely used yet due to the lag in implementing robotics in U.S. shipyards.

STATE OF THE ART:

The best state of practice in the best U.S. shipbuilders rivals the state of the art worldwide.

STATE OF RELATED INDUSTRY:

Heavy equipment manufacturers currently apply many of the same approaches for FCAW as do shipbuilders. FCAW is a dominant welding method for structural connections for building and bridge erections in some parts of the United States.

ENABLING TECHNOLOGIES:

To meet ongoing requirements for increased productivity, shipbuilders need to rely on continued advancements in FCAW process controls, consumables, and power supplies to improve process robustness (e.g., increase throughput, reduce inspection); increase deposition rate; and control deposition and heat input to accommodate new steel developments and design (weld size) requirements. Shipyards would also benefit from advances in emerging technologies that integrate welding engineering with other ship design and production processes, such as:

- Advances in statistical process control and numerical advancement approaches to allow the rapid development, qualification, and application of welding procedures.
- Automated storage, retrieval, and selection of welding procedures and process information.
- CAD technology which includes weld process requirements (e.g., material selection, joint design, access for welder or process automation), and accommodates weld-induced residual stress and distortion into the ship product model.
- Improvements in cutting, beveling, fitting, and accuracy control to produce accurate, repeatable joint preparations that are easier to weld by manual or automated FCAW.
- Reduction in the production of or improvements in the extraction of welding fume. In addition, emerging OSHA and EPA regulations pertaining to worker's exposure to chromium, manganese, and nickel will significantly impact the ability of shipbuilders to use these processes.

MANUFACTURING STRATEGIES:

FCAW advancements are driven by:

- Changes in steelmaking practices which require different filler metal chemistries and welding heat inputs for meeting structural requirements.
- More stringent design and product requirements for fairness and dimensional control. This advancement demands a more precise control of weld size and heat inputs.
- Increased difficulty in hiring and training qualified welders, which requires high levels of process robustness to accommodate welders of varying skill levels.
- Increased levels of mechanization and hard automation, which also require high levels of process robustness.
- Incorporation of welding into the shipbuilding enterprise. Welding process requirements and impacts must be incorporated into the electronic ship product model.

The U.S. shipbuilding industry is represented as a small percentage of the welding equipment and filler metal market. As a result, the shipbuilding industry needs to take advantage of developments driven by other industries. The ultimate choice would be to purchase welding consumables produced under commercial specifications, as this would significantly reduce material costs.

Submerged Arc Welding

INTRODUCTION:

Submerged arc welding (SAW) is a process that produces coalescence of metals by heating them with an arc (or arcs) between a bare metal electrode (or electrodes) and the work pieces, and obtains shielding by a blanket of granular, fusible material on the work piece. By using special equipment, shipyards have refined this technique so that all welding can be performed from one side and the cost of turning completed panels is avoided.

The first real production application of SAW was to support the U.S. war effort by quickly constructing ships during World War II. Since then, SAW has grown in popularity for many applications at shipyards. Both U.S. and foreign shipyards use this process to make miles of flat position welds in panel shops, platens and on ship assemblies, when possible.

STATE OF THE INDUSTRY:

In shipbuilding, the primary use of SAW is in the joining of plates to produce panels for hulls and bulkheads. This process is typically applied by specially designed panel welders who incorporate plate positioning, weld joint backup, and mechanized welding. As a result, plates as thick as 30 mm can be welded from one side in a single pass by simultaneously employing multiple electrodes. In addition, almost all U.S. shipyards are using SAW to weld erection joints by mechanizing the process' various types of tractor units.

Some T stiffeners are fabricated from plates using the process, whereby double fillet welds are simultaneously applied by systems that hold the web and flange in the proper position for welding in the horizontal fillet position. In some cases, SAW may be used for the attachment of stiffeners to hull panels.

Through SP-7 funding, procedures have been developed for the use of SAW for one-side welding of erection joints, using a combination flux/copper backing and the addition of iron powder for joint filling. The methods for this application have received American Bureau of Shipping approval and have been successfully used in a field application at National Steel and Shipbuilding Company.

STATE OF THE ART:

The state of the art for SAW does not vary widely from industry to industry. Some enhancements have been made in power source, joint tracking, volumetric analysis, automatic adjustment, and welding head improvements/developments in the area of welding consumables. These enhancements are minor in terms of advancing the SAW technology beyond its current application.

STATE OF RELATED INDUSTRY:

SAW is well suited for the joining of thick sections of carbon and low alloy steels. Consequently, the process has a wide range of uses in various industries and applications. Other related applications where SAW is currently used include pressure vessels; heavy wall large diameter piping; boiler waterwalls; field-erected steel storage tanks; and structural steel plate and box girders for buildings and bridges.

SAW is most effective when applied in a flat welding position. This trait becomes a major limitation because most of the horizontal seams in steel storage tanks, welded by SAW, require specially designed equipment to provide support of the granular flux, as it provides the necessary shielding in this position. This same technique could be applied for the welding of ship joints in this same position during fabrication.

ENABLING TECHNOLOGIES:

Enabling technologies would primarily be limited to those which provide advancements in equipment and consumables. One way to improve productivity is to develop steelmaking technologies that produce steels that would permit the use of welding processes with higher heat inputs and deposition rates. Currently, weld properties are acceptable, but base material properties degrade at high heat inputs.

MANUFACTURING STRATEGIES:

Manufacturing strategies for SAW would include the implementation of designs and practices that allow for a greater use of this very high productivity process, even during the erection stages of shipbuilding.

Gas Tungsten Arc Welding

INTRODUCTION:

Gas tungsten arc welding (GTAW) is a process that produces coalescence of metals by heating them with an arc between a non-consumable tungsten electrode and the work pieces, and obtains shielding by a gas. The shielding gas is fed through the torch to protect the electrode, the molten weld pool, and the solidifying weld metal from atmospheric contamination. GTAW has also been developed to provide a finely controlled weld puddle for more critical applications.

GTAW produces superior quality welds and can be used to weld almost any metal. Its ability to independently control the heat source and filler metal additions provides excellent control of root pass weld penetration for critical applications. Although it is not considered a high deposition process, GTAW can effectively be used on thin sheet metal, piping, or critical connections. All shipyards use this process.

STATE OF THE INDUSTRY:

In the shipbuilding industry, GTAW is often used for pipe connections. The process provides high quality weld deposits which are critical for pressure piping. GTAW can be applied manually or by mechanized orbital welders. This flexibility makes it suitable for the pipe shop on-board ships.

Due to low deposit rates, GTAW is not used to weld plate or structural members. Additionally, this process has difficulty in properly shielding the weld zone in drafty environments. Special care should be taken to eliminate drafts in an open environment.

STATE OF THE ART:

Industries with critical welding applications (e.g., aerospace industry) rely heavily on the GTAW process. As a result, these industries employ automatic controls, vision sensors, penetration control sensors, seam trackers, and arc length controls to ensure the highest weld quality obtainable.

Numerous improvements in welding power sources, including inverters and pulsed/variable polarity AC, are available. Shielding gas mixtures have also been identified for improved welding performance. Orbital gas tungsten arc welders provide consistent, controllable performance for pipe welding.

STATE OF RELATED INDUSTRY:

In some industries, GTAW has similar applications to those in shipbuilding. For example, manufacturers that make equipment for the International Space Station rely heavily on this process for the precise welds required in tubing and pipe lattice designs. On the other hand, heavy manufacturing industries, such as construction equipment manufacturers and pressure vessel manufacturers, rarely use GTAW except for pipe connections.

ENABLING TECHNOLOGIES:

Enabling technologies include:

- GTAW flux for increased weld penetration and reduced distortion to provide increased potential for the GTAW process. This flux greatly increases penetration which, in turn, decreases the amount of distortion by reducing the required total heat input. Costly joint preparation requirements for thicker section welding are also reduced.
- Improvements in penetration control systems, vision sensors, and seam trackers will provide more accurately welding critical components. In the past, these types of control systems have not been proven to be sufficiently rugged to withstand the shipyard work environment.
- Cold wire and hot wire filler metal feed systems to improve deposition rates.

MANUFACTURING STRATEGIES:

The overall quality and productivity of GTAW can be increased by implementing the use of orbital welding equipment, GTAW fluxes, penetration control systems, and other process sensors. Although it is a high quality welding process, GTAW is rarely used in heavy manufacturing due to its inherently low deposition rate. The identification of critical welds such as in piping and pressure containment are candidates for the GTAW process.

Stud Welding

INTRODUCTION:

Stud welding (SW) is a process that produces coalescence of metals by heating them with an arc between a metal stud or similar part and the work pieces. This process can be performed manually with the use of a hand-held welding gun or by mechanized equipment for high production applications. SW can involve other welding processes including arc, resistance, friction, and percussion.

STATE OF THE INDUSTRY:

SW greatly facilitates the attachment of mounting devices such as insulation pins, pipe hangers, and light foundation threaded fasteners. This process is very simple in its design, and can effectively and economically provide a quality attachment. SW is on a steady growth curve in shipyards. Each year, new applications are being developed to implement stud welds. For example, shipyards are now using SW to secure attachment pins for alignment tooling during the fitting process.

STATE OF THE ART:

Commercially available SW equipment is consistently applied across industries.

STATE OF RELATED INDUSTRY:

Related industries (e.g., bridge and building construction) heavily rely on SW for the attachment of thousands of shear connectors. Many household appliances require stud welds to attach bolt connections.

ENABLING TECHNOLOGIES:

While reliable, SW is sensitive to the material and the surface condition of the components being joined. For manual applications, the equipment and associated cabling are fairly heavy. Operator fatigue can result in misalignment of pins and poor weld quality. Newer technologies, such as friction stud welding, permit easier attachment of dissimilar and hard-to-weld materials, and may be used underwater to support the oil industry. Power supplies are being developed with the capacity to store multiple programs and provide electronic controls for the process. To facilitate the application of small diameter pins for insulation, an automatic feed system has been developed in a recent NRSP SP-7 funded project. This system provides numerous pins to the gun without requiring the operator to load each pin individually. Lighter

weight guns and power supplies can be developed to take advantage of newer lightweight, heat resistant materials and microprocessor technologies.

MANUFACTURING STRATEGIES:

SW continues to find new applications as the productivity and effectiveness of the process increases. The process provides a wide range of flexibility in the type of components which can be attached, and can reliably be implemented with a minimum of training.

Electrogas and Electroslag Welding

INTRODUCTION:

Electrogas welding (EGW) is a process that produces coalescence of metals by heating them with an arc between a continuous filler metal electrode and the work pieces. Electroslag welding (ESW) is a process that produces coalescence of metals with molten slag that melts the filler metal and the surfaces of the work pieces. These high deposition processes were commonly used to join the long vertically positioned joints in ships with a relatively flat-side shell profile. Both welding methods start at the bottom of the joint and continue vertically upward as the welding process proceeds, thereby filling the joint with a single pass. Although their use is declining due to new ship designs and alterative methods, EGW and ESW welding are gaining popularity in the bridge and building construction industries.

STATE OF THE INDUSTRY:

In the United States, only one shipyard still uses EGW and ESW for ship construction. This shipyard produces prototype double-hull blocks for tanker construction. A unique design, combined with the EGW process using flux-cored electrodes, allows for the welding of more than half of the primary welds of this ship structure. The ESW process has been adapted to the cladding of propulsion shafts, as a substitute for sleeving the shaft with a dissimilar material.

STATE OF THE ART:

In the past, many industries used or experimented with either EGW or ESW. However, the inherently poor mechanical properties of the completed welds tended to outweigh the productivity benefits of these processes. The effort came to a standstill in 1979 when the failure of an ESW weld in a major interstate bridge girder nearly caused the total failure of the bridge. Since that time, the bridge industry has banned the use of ESW. The negative publicity curtailed the use of both processes, except in those cases where the expected weld properties were considered adequate for a given application.

Several years ago, the Lincoln Electric Company introduced its vertishield process, a self-shielded, flux-cored electrode version of EGW. The vertishield process has been used for a limited number of structural applications. Within the past few years, the Federal Highway Administration has funded research for an ESW version that can produce welds with properties acceptable for bridge construction. The version employs a very narrow joint root opening so that the overall heat input required is significantly less, resulting in dramatic improvements in mechanical properties.

STATE OF RELATED INDUSTRY:

Although not extensively used, EGW and ESW have a few minor applications in other industries. Most of these applications involve the joining of thick castings or plates, where resulting mechanical properties are not of great concern.

ENABLING TECHNOLOGIES:

Enabling technologies of EGW and ESW would include the further development of consumables and techniques that would result in mechanical property improvements.

MANUFACTURING STRATEGIES:

The consumables and techniques of EGW and ESW need to be further developed to satisfy the performance requirements of shipbuilding regulators. Once achieved, the ship structures would then need to be redesigned to permit implementation of these high productivity welding processes.

Plasma Arc Welding

INTRODUCTION:

Plasma arc welding (PAW) is a process that produces coalescence of metals by heating them with a constricted arc between an electrode and the work piece (transferred arc), or between the electrode and the constricting nozzle (non-transferred arc). The arc is constricted by passing it through a water-cooled orifice. The orifice gas forces the arc through the orifice, which becomes ionized and produces a plasma jet. The arc also has a higher energy density due to the constriction and plasma gas velocity. Shielding is obtained from the hot, ionized gas issuing from the torch which may be supplemented by an

auxiliary source of shielding gas. PAW has proven to be very robust for high volume automation welding operations due to its recessed tungsten electrode, which provides longer operating times.

While similar to GTAW, PAW has some advantages. PAW uses a pilot arc established between the electrode and the constricting nozzle, which eliminates the need for high frequency to start the arc for each weld. Its tungsten electrode is recessed within the torch, thereby protecting it from contamination compared to the open electrode of GTAW. Additionally, plasma is less sensitive to torch standoff and can achieve faster welding speeds than GTAW. One possible drawback is the larger torch size that may lead to accessibility problems.

STATE OF THE INDUSTRY:

PAW is not commonly used in the shipbuilding industry. Practical applications are usually limited to pipe shops and the welding of ductwork. GTAW has proven to be more flexible for the range of applications in shipyards. Mechanization and automation, such as orbital tube and pipe welding equipment, have typically been built based on the GTAW process.

STATE OF THE ART:

The state of the art variation of PAW, known as variable polarity plasma arc (VPPA), may prove feasible in the shipbuilding industry. VPPA has been used for joining thick-section aluminum in rocket boosters and casings with high quality welds. This approach may show application for aluminum platework in the shipyards. Accurate fit-up is required for this application.

STATE OF RELATED INDUSTRY:

PAW has primarily been applied in the aerospace and household appliance industries, as well as some automotive applications. The process has lent itself to high production automation systems in these industries.

ENABLING TECHNOLOGIES:

PAW has proven to be very robust for high volume automation welding operations due to its recessed tungsten electrode, which provides longer operating times. The directionality of the arc and its relative insensitivity to torch standoff enables it to achieve high weld quality and fast welding speeds.

MANUFACTURING STRATEGIES:

Unlike related industries, PAW has yet to draw support in the shipbuilding industry. This resistance may be due to the process' lack of flexibility compared to GTAW, and to the shipyards' lower volume of similar components. PAW is not readily available in the typical forms of mechanization and automation as used by the shipyards.

Brazing

INTRODUCTION:

Brazing is a process that produces coalescence of materials by heating them to the brazing temperature in the presence of a filler metal having a liquidus above 840°F (450°C) and below the solidus of the base metal. This process differs from other joining methods in that the brazing does not melt the base metals being joined, thereby allowing dissimilar or difficult-to-weld materials to be joined.

STATE OF THE INDUSTRY:

Brazing is primarily used in the U.S. shipbuilding industry to fabricate copper and copper alloy piping on-board ship for plumbing or heating/air conditioning installations. Additionally, the process is used to join almost all of the traditional materials used for ship piping. The most common method of brazing joints is the oxy-fuel torch process. Usually manipulated by hand, the parts are heated to the proper temperature so that the brazing material will flow between two surfaces to complete the joint. Brazing in ship applications differs from that of the automotive industry in that the latter uses this process for the fairing of surfaces.

STATE OF THE ART:

The state of the art involves the brazing materials and techniques being used and developed in the aerospace industry for very critical applications.

STATE OF RELATED INDUSTRY:

In some related industries, brazing is automated and may use induction heat or infrared sources. These applications are typically small in size and have a large family of similar parts. One of the largest, single industrial applications of brazing is the joining of copper piping in commercial applications such as heating and air conditioning equipment. Like most of the welding processes, the ASME Boiler and Pressure Vessel Code recognizes brazing as a viable

method for joining certain piping and pressure vessel components of high pressure service.

Another significant usage of brazing is the joining of dissimilar metals; metals to nonmetals; or metals and metal combinations that do not lend themselves to welding with conventional methods. The jet engine industry relies on this capability of brazing to join critical components; however, most of its brazing is done in a furnace or under more controlled conditions than is possible with standard torch brazing.

ENABLING TECHNOLOGIES:

Enabling technologies would involve those which lead to improvements in consumables or equipment.

MANUFACTURING STRATEGIES:

Because of the unique design of braze joints, greater use of this process would require redesign of components.

Laser Welding

INTRODUCTION:

Laser welding (LW) is a process that produces coalescence of materials with the heat obtained from the application of a concentrated coherent light beam impinging on the joint. This process can be performed autogenously or through the use of filler metal additions in the form of wires, preforms, or metal powders. Filler may be used to modify the metallurgy or to aid in bridging gaps caused by poor fit-up. Depending on beam power and quality, weld penetrations over one inch may be obtained. The high speed, low heat input, and precision of LW results in low thermal distortion.

Many different materials can be laser welded, including materials and combinations that are considered only marginally weldable with conventional arc processes. With the advent of using fiber optics to transport the light beam to the work, rather than having the part move under the beam, possible applications for LW include in-situ repair work, beam to plate joints, and pipe welding. Over the next several years, the use of LW is expected to increase in ship construction.

STATE OF THE INDUSTRY:

LW has seen only limited applications in U.S. shipyards. While construction costs are a major driving factor in using manufacturing methods, LW has lagged in application because of its high cost of equipment and lack of accepted qualification standards. Recently, however, LW was used to fabricate tee stiffeners for the fabrication of corvettes. Additionally, laser welded angles, tees, and cruciform sections were used in DDG HEPA filter arrays. Laser-welded, corrugated-core sandwich panels have also been installed as antenna platforms on the *U.S.S. Mt. Whitney*. The panels are being evaluated in this pilot project as a possible lightweight replacement for traditional, beam-stiffened plate designs for bulkheads, decks, and doors.

In Europe, the use of laser welded structural elements and sandwich panels is also increasing. Currently, two European shipyards (Meyer-Werfft and Fincanteri) have implemented LW into their production. Odense (OSS) has attained ABS qualification for hull welds in steel, and has recently started production welding as well. A major laser installation is scheduled to go into production at Blohm & Voss early in 2000. The Japanese Welding Research Institute is also evaluating the use of LW for aluminum ferry decking.

STATE OF THE ART:

High speed and controlled heat input, combined with the ease of automation, make LW an excellent choice for precision manufacturing applications. Refractory alloys are laser welded for high temperature aerospace and satellite applications, and transmission components are laser welded at high production rates with high reliability. Medical devices, electronic packages, and automobile air bag housings are laser sealed without heat effects to the internal components. Laser-deposited cladding provides a metallurgical bond with minimum dilution and superior properties in the clad materials.

STATE OF RELATED INDUSTRY:

Traditional heavy fabrication industries have not yet adopted LW on a wide scale. However, some industrial applications which reflect the high production requirements of long welds (typical of shipyards) do exist.

- As part of the production process for building railroad locomotives, GE Transportation Systems regularly laser welds components up to 0.750 inch in production.
- The automotive industry fabricates tailored blanks, where sheets of dissimilar composition, coating, or thickness are combined into a single blank for stamping into door panels and other automotive components.

- Japanese manufacturers have qualified LW for production of structural members (e.g., tees, box beams, tubing) as well as the production of stainless steel piping for sour gas service.
- A Japanese steel company is using LW to join one-foot plates. This application requires preheating of the plate.

ENABLING TECHNOLOGIES:

Continued successful implementation of LW in European shipyards, as well as routine acceptance by ship classification societies, will help reduce barriers in U.S. shipyards. However, some factors remain to be addressed before U.S. implementation is widespread:

- Pre-Processing — Accurate joint fit-up is critical to successful LW. Ship classification societies have established that shipbuilders must demonstrate their ability to produce weld preparations precisely and repeatably in production as a criterion in LW process qualification. Considerations must be made for the edge alignment, the fit-up tolerances, and the expected lower travel speeds to determine the efficiency of this process for ship panel fabrication. Current implementations of heavy-section LW include milling of the steel plates to achieve required tolerances. Specifications for incoming material fairness/flatness must also be tightened, and steel chemistry requirements may also need modification.
- Process Modification — In high yield steels, special filler wires or other techniques may be needed to meet stringent U.S. Navy and commercial toughness requirements.
- Power Level — High power CO_2 lasers are the dominant lasers for heavy-section applications due to the higher power levels available. Nd:YAG lasers can deliver a beam through flexible fiber optic cables which aids in automation, but power levels and beam quality have not been sufficient for most anticipated applications. The advent of higher power Nd:YAG lasers with improved beam quality (four-kW and five-kW models are becoming available) will greatly enable the automated application of LW on a large scale, and in almost any area of the vessel for fabrication and repair. Advancements in the power-level technology are also being driven by needs in other industries. Improvements are expected to be forthcoming.
- Design for Manufacturing — Critical to the ultimate success of LW are optimal joint designs; design for beam access and processing; and integration of LW with material handling and other shipyard processes. Additionally, a catalog of standardized joints and components will help reduce the amount of system programming required. These elements need to be incorporated into the shipyard's designs, product models, process planning, and electronic resource planning/manufacturing resource planning. Presently, the supporting data, requirements, and implementation technologies are not available.

MANUFACTURING STRATEGIES:

The speed, quality, accuracy, and minimal distortion provided by LW make it extremely appealing for shipbuilding applications. Increases in processing rate and the ripple effects in improved productivity in downstream assembly processes could justify the capital investment required for implementation, and provide a significant competitive advantage in worldwide markets.

Electron Beam Welding

INTRODUCTION:

Electron beam welding (EBW) is a process that produces coalescence of metals with the heat obtained from a concentrated beam composed primarily of high velocity electrons impinging on the joint. Initially used as a commercial welding process in the late 1950s, the process was quickly recognized as a method for making high quality, deep penetrating welds on critical parts.

EBW features three basic methods: high vacuum; medium vacuum; and non-vacuum (EB-NV). The major difference among them are the achievable weld bead shape. Due to the large components required for ship construction, EB-NV is the most practical in the shipbuilding industry. The required vacuum chamber size for the vacuum EBW methods are extremely expensive and time consuming due to the pump-down cycle. Although the vacuum chamber is not required for EB-NV, some type of radiation shielding must still be provided to protect personnel from the x-rays generated.

STATE OF THE INDUSTRY:

Currently in the shipbuilding industry, EBW is only being used on selected, high-integrity pressure vessel welds in ship propulsion systems.

STATE OF THE ART:

Continuous improvements in EB-NV gun designs and process controls, coupled with recent developments in nozzle design techniques, have greatly increased the EB-NV system's stability and reliability. Narrow, low distortion welds formerly considered to be weldable only in a vacuum are now within the capability of EB-NV. The use of helium as a shielding gas reduces the local atmosphere density, resulting in less beam dispersion or spread. Deeper penetration and higher travel speeds can also result from the use of helium.

STATE OF RELATED INDUSTRY:

EB-NV is used in the pressure vessel industry for thick-section welding, and is continuing to gain acceptance in the high production automotive industry. Aluminum intake manifolds, transmission carrier assemblies, and torque converters have all benefitted from EB-NV.

ENABLING TECHNOLOGIES:

Nozzle developments for the vacuum-to-atmosphere orificing have greatly increased the EB-NV system's stability and reliability. A minor modification to the orifice system, which permits the use of helium, has substantially increased the beam throw (the ability to weld at greater work distances). A new, narrower, deeper penetrating weld has also become the EB-NV standard.

MANUFACTURING STRATEGIES:

Substantial rewards may be achieved through further investment in the EB-NV process for cases where narrow, deep penetrating, low distortion welds are required. Non-vacuum air welds provide a decrease in transverse shrinkage compared to arc welds, and the use of helium gas shielding decreases the transverse shrinkage even further. Implementation of EBW in general shipbuilding is foreseen as being limited to a small suite of applications where weld quality and integrity is critical, or in applications where extremely thick-sections are to be joined.

Friction Stir Welding

INTRODUCTION:

Friction stir welding (FSW) is a solid-state process that produces coalescence of materials under the compressive contact force of a rotating tool and the work pieces, moving relative to one another to produce heat and plastically displace material from the faying surfaces. The solid-state low distortion welds are achieved with simple, energy-efficient mechanized equipment. This low-cost process enables butt and lap joints to be made in low melting point materials (e.g., aluminum alloys) without the use of filler metals.

FSW joins materials by plasticizing and then consolidating the material around the joint line. First, a hole is pierced at the start of the joint with a rotating steel pin. The pin continues rotating and moves forward in the direction of welding. As the pin proceeds, the friction heats the surrounding material and rapidly produces a plasticized zone around the pin. Pressure provided by the pin forces plasticized material to the rear of the pin, where it consolidates and cools to form a bond.

STATE OF THE INDUSTRY:

FSW was developed for the European market, specifically for high-speed aluminum ferries where corrugated aluminum extrusion are joined longitudinally to fabricate automobile deck structures. Although development work for steel applications is currently ongoing, the technology requires further advancements before FSW because useful in these shipyard applications. Presently, more than 30,000 meters of weld have been produced in aluminum panel structures without a defect.

STATE OF THE ART:

FSW's most sophisticated application is in the fabrication of Delta-family rocket boosters. The FSW process has replaced the arc welding of longitudinal welds on the Delta II booster, and will be used to produce the new Delta IV evolved expendable launch vehicle. The first FSW booster was launched in August 1999. Aerospace manufacturers are currently exploring FSW of aluminum for primary aircraft structure and higher-performance materials in aircraft and aircraft engine applications.

STATE OF RELATED INDUSTRY:

The automotive and heavy manufacturing industries are beginning to explore FSW in both aluminum and steel applications, but technology has yet to be implemented.

ENABLING TECHNOLOGIES:

New developments that would enhance the use of FSW include:

- Technology to produce welds in curvilinear paths.
- Technology for thicker-section (over one inch) aluminum welding.

- Technology for higher performance materials such as higher performance tools and higher processing loads.
- Process data to qualify FSW for ABS and U.S. Navy acceptance.
- Process models to predict weld performance and specify process parameters.

MANUFACTURING STRATEGIES:

FSW's ability to produce long, linear solid-state welds in plate materials provides a range of opportunities in shipbuilding. One benefit of this process is its ability to make seam welds on aluminum alloys that cannot readily be fusion welded without over-designing the joint. For age-hardenable aluminum alloys, joint efficiencies of 90% can he achieved. In comparison, the best available welding technologies can only achieve joint efficiencies of 50% for these materials.

Preliminary research into applying FSW to steels, stainless steels, and other high-performance alloys indicates that the process may be similarly productive and less sensitive to base metal composition in steels as it is in aluminum. In addition, solid-state welds are not subject to hydrogen contamination which contributes to embrittlement and cracking. Therefore, higher-strength steels welding (currently subject to stringent and expensive process qualification and control requirements) could be performed more efficiently and effectively.

The solid-state bonds are produced at temperatures significantly lower than arc welds. Since heat inputs are significantly lower than those of traditional arc welding processes, thermally-induced distortion (highly problematic in welding thin residual stress and distortion) is reduced or eliminated. No joint preparation is required, and weld fumes; spatter and hot-cracking; and gas porosity are absent. In addition to minimal loss of base metal mechanical properties, the reduction in corrosion properties is also minimal. As a result, more efficient structures can be designed which take advantage of improved weld properties. Fabrication costs can also be significantly reduced due to the lowered requirements for process control and qualification.

Resistance Welding

INTRODUCTION:

Resistance welding (RW) is a process where the coalescence of metals is produced by the heat generated by the resistance of the metal to the passage of electric current. This process is ideal for overlapping sheet metal connections.

STATE OF THE INDUSTRY:

In ship construction, RW is used for ventilation work, joiner work, and other sheet metal operations. Most of these applications do not challenge the limits of this technology. For the most part, RW is performed efficiently and effectively.

STATE OF THE ART:

The automotive and light manufacturing (e.g., appliance) industries are, by far, the leaders in high-production RW. Here, the process is applied to a variety of steels with various coatings to produce a wide range of simple and complex components. Sophisticated feedback control systems allow the welding of multiple sheet stack-ups. Automated weld cells can produce more than 100 spot welds in a single weld cycle.

STATE OF RELATED INDUSTRY:

Off-highway equipment manufacturers and fabricators apply RW to a similar class of sheet metal applications, in much the same manner as shipbuilders.

ENABLING TECHNOLOGIES:

The state of the art of RW equipment is sufficient for current shipyard applications.

MANUFACTURING STRATEGIES:

RW will continue to be applied in shipyard sheet metal applications.

Thermal Spraying

INTRODUCTION:

Thermal spraying is a process in which finely divided metallic or nonmetallic surfacing materials are deposited in a molten or semi-molten condition on a substrate to form a spray deposit. The three most commonly used methods are electric arc spraying (EAS); high velocity oxy-fuel (HVOF) spraying; and atmospheric plasma spraying (APS).

EAS uses a wire consumable, and can spray any material which can be fabricated into a wire, including solid, metal-cored, or flux-cored wires. Consequently, wear or corrosion coatings can be produced, and the parts can be rebuilt with a wide range of alloys. EAS is characterized by coating porosity levels in the 5% to 10% range with fairly low bond strength between the coating and the substrate (typically two to seven ksi).

HVOF uses a powder consumable, and can spray any material which can be produced as a powder. Consequently, wear or corrosion coatings can be produced, and the parts can be rebuilt with a wide range of alloys. HVOF is characterized by coating porosity levels in the 1% to 2% range with high bond strength between the coating and the substrate (typically 10 to 14 ksi).

APS can use either wire and powder consumables. Consequently, wear or corrosion coatings can be produced, and the parts can be rebuilt with a wide range of alloys. APS is characterized by coating porosity levels in the 1% to 2% range with intermediate bond strength between the coating and the substrate (typically seven to ten ksi).

STATE OF THE INDUSTRY:

Various thermal spray processes are used in ship applications, typically for corrosion protection of steel surfaces and the restoration of machined surfaces that may be worn, eroded, or corroded. Although the most common method of application is flame spraying, the shipbuilding industry also uses EAS and HVOF techniques. Another option is APS, but it has a limited extent compared to the other processes. Typical applications in shipbuilding and repair include pumps, valves, bearings, and shafts in rotating equipment. Coatings deposited include stainless steels and nickel alloys for corrosion protection, and tungsten carbide cobalt coatings for wear protection.

STATE OF THE ART:

State of the art spraying systems include high energy HVOF systems (typically 200 kW) which can spray high quality coatings at high deposition rates. These systems are often used in applications such as coating large rolls for papermaking and printing equipment. The latest HVOF equipment is capable of spraying wires rather than higher cost powders. Developments in HVOF flame technology have also included liquid fuels (e.g., kerosene). This technology reduces spraying costs by using kerosene/air mixtures rather than traditional gas/oxygen or kerosene/oxygen mixtures. Also available are higher energy plasma spraying systems, suitable for spraying multiple wires simultaneously for high deposition rate coatings. Few developments have occurred in flame spray or arc spray equipment in recent years.

STATE OF RELATED INDUSTRY:

In related industry, the most commonly used thermal spray processes are EAS, HVOF, and APS. HVOF has a broader use in industry compared to shipbuilding, mainly because a wider range of applications, environments, and coatings are available. Additionally, high energy HVOF and high energy APS equipment are extensive used for applications requiring high deposition rates over large areas being coated. EAS is well developed for corrosion protection of large offshore structures and pipelines in seawater environments with aluminum and aluminum-zinc coatings. Thermal spraying is a technology which has not been exploited for large-scale protection of ship structures in the shipbuilding industry. Lifecycle costing for painting versus thermal spraying is an another issue that needs to be examined.

ENABLING TECHNOLOGIES:

For field deployment of thermal sprayed coatings, a manual spraying technique is usually employed. Low level mechanization can be applied by using simple track-mounted spraying heads. Mechanization and automation are more common in shop-based spraying operations, often within a spray booth. Typical equipment include single axis track-mounted systems; X-Y coordinate positioning systems; and articulated arm robots.

MANUFACTURING STRATEGIES:

The results achieved through thermal spraying depend heavily on the quality and cleanliness of the surface preparation performed on the substrate material or part to be sprayed. The stripping of old coatings or removal of corrosion products prior to surface preparation by grit blasting is important to ensure the quality of the resultant coating, particularly to the adhesive bond strength between the coating and the substrate. An effective alternative technique is to use a bond coat, typically Ni-Al in the form of an arc-sprayed or flame-sprayed wire. The required coating can then be applied directly to the bond coat.

Polymer Joining

INTRODUCTION:

Polymer joining is a variety of processes used to join polymer materials such as plastics and composites. The processes include adhesives; hot plate; hot gas; resistive and induction implant welding; friction welding; and laser and infrared welding. The selection of method is dependent on the polymer chemistry, the joint designs, and the service requirements.

Welding and joining processes can replicate base metal strength in joints. The alternative is mechanical fastening which means the joints must be over-engineered to accommodate the fastener holes.

STATE OF THE INDUSTRY:

With the advent of newer ship designs implementing polymers (e.g., plastic pipe, tankage), technologies for joining these materials are now being introduced into shipyards. Fiberglass boat builders successfully apply a variety of processes during ship fabrication. Some of these approaches have been employed for nonmetallic structures on U.S. Navy minesweepers.

STATE OF THE ART:

The automotive and light manufacturing industries perform millions of plastic welds each year using various processes. Much of the low-pressure, natural gas transmission lines in residential neighborhoods are PVC piping, which is routinely welded and adhesive bonded. The aerospace industry has developed workable approaches for joining high-performance, polymer-matrix composites to avoid the use on mechanical fasteners, which degrades joint performance.

STATE OF RELATED INDUSTRY:

Polymer joining has limited use in the heavy fabrication industries.

ENABLING TECHNOLOGIES:

As polymer-matrix composite materials are implemented into ship structures, low-cost efficient joining processes for these materials will need to be developed. Among them are processes for polymer-to-metal joining to assist in the implementation of polymers in shipbuilding; using composite materials as a viable alternative for patching and repairing steel structures; and non-destructive evaluation techniques for polymer bonds. Additionally, each process would need to be able to withstand the rugged environments of the shipyard for manufacture and on-board ship for repair issues.

MANUFACTURING STRATEGIES:

Plastics joining techniques will follow the implementation of polymers into ship designs. Advantages include low weight, superior corrosion performance, dimensional stability, and minimal magnetic signature.

Robotics

INTRODUCTION:

Robotics is the technology dealing with the design, construction, and operation of robots in automation. A robot is an automatically controlled, reprogrammable, multi-purpose manipulator that operates in three or more axes, and performs defined tasks within its working envelope. Design for automation and continuous improvement in robotics are helping to enhance and foster this technology in many industries.

Robotics were initially used to move packages from one location to another. Since a robot could hold a material gripping tool, reasoning followed that it could also hold a welding or cutting torch. From this start, the use of robots for cutting and welding has spread virtually throughout all industries. However, the introduction of welding robots into shipyards has been at a slower pace. The accuracy of early robots was sufficient for resistance spot welding, but inadequate for the quality needed in arc welding. Today, the applications for welding robots are growing in the U.S. shipbuilding industry with improvements in software and hardware of robotic systems. Improvements in off-line programming, sensing technology, and mechanical system design have all contributed to the recent introduction of robots into the U.S. shipyards.

STATE OF THE INDUSTRY:

Robots are now used for welding small piece parts such as pipe hangers, tie-down fittings, ladders, and scuttles. These high volume parts are excellent candidates for robotic work. Other systems are now being used to make structural plate parts that require more advanced programming technology.

In other parts of the world, shipyards are using welding robots more extensively than in the U.S. shipyards. Many of these shipyards have greatly endorsed the concept of robots for large panel applications, while others have eschewed the practice almost entirely. To date, the major applications have been in profile cutting and marking; panel lines (e.g., large, micro, curved panels);and egg-crate welding operations. Some shipbuilders have found success in the implementation of portable robotic systems for many subassemblies. In these cases, the implementation was developed in the context of a specific product line with a dedicated processing plan and a facility tailored to the application. Currently, portable robotic systems do not appear to offer a

solution for in-place replacement of individual welders in most applications.

Many U.S. shipyards have not invested in the accuracy control requirements necessary for robotic welding. The tolerances on as-purchased mill rolled shapes are not sufficient for robotic welding without the addition of advanced sensors and tracking systems. Adopting the extra process control technology significantly increases the cost and effort required for robot implementation. For cutting applications, many U.S. shipyards have followed the lead of the European shipyards, and now use robots to cut the various structural profiles required for ship construction.

STATE OF THE ART:

The largest market for welding robots is in the automotive industry. Much publicity has documented this industry's use of robots for resistance welding applications. Arc welding robots are also used extensively in the fabrication of automotive frames, car seats, and other components. Robotic and automated processes are the preferred method of assembly at the prime and sub-tier supplier levels. Design for automation has been incorporated into the product development process. A robust supplier base of robot manufacturers and tooling designers exist to support these efforts.

STATE OF RELATED INDUSTRY:

Related heavy manufacturing industries (e.g., construction equipment and farm implement companies) have been using some level of robotics for welding since the 1970s. Although they are taking advantage of the continuous progression of robotic hardware and software improvements, these companies have invested in technologies that bring accuracy control requirements to their parts which are necessary for robotic welding.

ENABLING TECHNOLOGIES:

Continuous improvements in robotic software and hardware are playing a role in bringing this technology to the shipyards. Further developments are required in off-line programming, sensing technologies, planning systems, and the integration of welding/cutting process knowledge into the CAD part information or within some level of planning/ management software. A continuous emphasis needs to be placed on construction design for manufacturability with automation.

MANUFACTURING STRATEGIES:

The use of robotics for cutting and welding will facilitate the drive toward JIT and CFM style material flow from raw materials to final assembly. Reduction and elimination of non-value added tasks should reduce cost and delivery. Full scale robotization of welding and its allied processes in any shipyard in the world is still some time away. The robot is only one element in the implementation of CIM into shipbuilding. Successful implementation of robotics has incorporated integration of the robotic software with shipyards' CAD and materials planning systems. Some of these systems required large investments in the material preparation of plates, profiles, and/or manufacture of subassemblies.

Automation

INTRODUCTION:

Automation is the technique of making an apparatus, a process, or a system operate by a self-regulating mechanism. Typical examples of single-purpose mechanized automation include portable tractors, fixed dedicated systems, sensor technologies, and small computer-based processors.

STATE OF THE INDUSTRY:

Single-purpose mechanized automation for welding and cutting operations is well established in the shipbuilding industry. Many of the fixed dedicated systems require minimal operator intervention during their execution. On the other hand, portable systems must be set up and torn down by the operator, and require repositioning and parameter adjustments during their operation. The selection of equipment is dependent on the welding or cutting process being employed, and the flexibility or motion required to complete the task. Newer forms of automation (e.g., those used to locate, tack, and weld stiffeners to panels) are more common in European shipyards than U.S. shipyards.

STATE OF THE ART:

Currently, a new generation of portable mechanized automation is appearing in the market. These systems are referred to as smart mechanization. In essence, they are two- to four-degrees of freedom systems which are controlled by small computer-based processors using servo or stepper motor technology. The smart mechanization systems can use available sensor technologies and programming to work

autonomously, after being placed in the global vicinity of the path to be followed for a particular process. With this capability, multiple systems can be set up and used by one operator.

STATE OF RELATED INDUSTRY:

Related industries' applications for automation are similar to those of the shipbuilding industry. Among these are structural fabrications for buildings, plants, highways, and construction equipment manufacturing. Shipyards have provided much effort in improving portable pieces of equipment to facilitate ease of portability, minimize set up/tear down, and improve robustness of components to make them more accommodating to production applications.

ENABLING TECHNOLOGIES:

The use of sensor technologies and onboard computer controls allow the smart mechanization systems to run autonomously or quasi-autonomously, rather than requiring operator intervention. These systems can control their position, and adaptively control the process if the proper sensor technologies are applied.

MANUFACTURING STRATEGIES:

Smart mechanization automation enables one operator to direct multiple systems. This approach should increase the productivity achieved per labor hour in production. As technologies advance, the productivity per unit labor hour should also increase.

Non-Destructive Testing

INTRODUCTION:

Non-destructive testing (NDT) refers to the inspection, analysis, or treatment of material without damaging or altering its initial state. Typical methods include surface examination, volumetric examination, radiographic testing, and ultrasonic testing.

All of the shipbuilding regulatory bodies require some amount of NDT for welds. Depending on the application and criticality of the weld joint, the inspection may involve surface examinations (e.g., visual, penetrant, magnetic particle) or through thickness volumetric examinations. Eddy current (electromagnetic) methods can be used for a variety of examinations including paint thickness gauging. However, this technique usually involves the evaluation of components, such as heat exchanger tubes, for service-related degradation.

Among the volumetric NDE methods applied for shipbuilding applications are radiographic and ultrasonic testing. Both methods can detect surface and subsurface discontinuities, but are primarily used to detect subsurface conditions. The volumetric inspection technologies are also being transformed by newer developments in automation, computerization, and electronic component advancements. Recent developments include systems that can store radiographs on computer discs, and ultrasonic inspection signals which can be reported in three dimensions using computer assistance.

STATE OF THE INDUSTRY:

Virtually all of the available NDE methods are used to some degree in the U.S. shipbuilding industry, primarily due to the requirements imposed by various regulatory bodies. Visual examination, the primary inspection method, is supplemented by other surface and volumetric methods where designs or standards dictate the need for more extensive evaluation.

Radiographic testing, typically employed using a radioactive isotope as the radiation source, is the most common method for volumetric examination. However, the use of ultrasonic testing is increasing since it can be applied more expediently; at a lower cost; and without the need for evacuation of the testing vicinity due to the inherent radiation hazard of radiography. Ultrasonic testing, in lieu of radiography, is of particular interest for applications such as submarine hulls, where the wall thicknesses dictate long radiographic exposures. The ultrasonic technique is typically applied manually, but new developments in equipment with computerized enhancements are leading to mechanized applications on a limited basis. The U.S. Navy is currently developing a knowledge-based inspection system that combines a mechanized scanner with a neural network. Not only does this arrangement detect discontinuities, but it also detects sizing and characterization to provide decision-making intelligence.

One area of interest to shipyards is the development of EMATS for surface and volumetric inspections. This method uses electromagnetic energy to generate ultrasonic waves in the test object. One major advantage is that the transducer need not contact the part, as is typically the case for standard ultrasonic techniques. Recent developments have also demonstrated this inspection method as useful for automated inspection of welds immediately following the welding torch.

STATE OF THE ART:

The development and application of NDE for post-fabrication quality verification are relatively advanced in all industries including shipbuilding. Additionally, technological advancements are being focused in the areas of:

- Increased mechanization/automation.
- Sensor application to monitor fabrication operations such as welding on a real-time basis.
- Greater computerization including the creation of systems integrating artificial intelligence.
- Development of techniques and systems for examining components on-line.
- Development of systems capable of providing global monitoring of components as opposed to more typical localized examinations.

STATE OF RELATED INDUSTRY:

The state of NDE in related industry is not substantially different than those of the shipbuilding industry. For applications or industry sectors which require very stringent evaluation, more specialized methods or enhancements are being applied to existing methods; however, if similar design or performance constraints exist in the shipbuilding industry, then those same techniques are quickly adopted and applied. In cases such as inspection of nuclear components for U.S. Navy vessels, the development of NDE technologies by the shipbuilding sector have preceded other industries.

ENABLING TECHNOLOGIES:

Enabling technologies are mainly related to improvements in the areas of automation and computerization. Like welding, an interest exists for developing NDE techniques that essentially eliminate the inaccuracies introduced by human error. Therefore, systems must be developed that synergistically provide information related to discontinuity type, size, and location. Additionally, sophisticated electromechanical systems are required which incorporate the necessary computational abilities to improve on human capabilities.

MANUFACTURING STRATEGIES:

The advancement and application of NDE has an indirect effect on manufacturing strategies. The simple application of NDE does not improve a manufacturing process nor does it provide a more defect-free, performance-enhanced component. However, improvements in NDE techniques could allow for a more reliable detection of critical flaws, which could eventually lead to relaxation of quality requirements because inherent conservatism is no longer required. Furthermore, the advancement of sensors and related feedback systems employed during welding operations may foster advancement from the defect detection mode into the realm of defect prevention (e.g., monitoring the process in real-time and adjusting it to prevent the occurrence of defects).

POINTS OF CONTACT:

For further information on SP-7 Panel items in this report, please contact:

Mr. Lee Kvidahl
Ingalls Shipbuilding
(228) 935-3564
kvidahllg@ingalls.com

Mr. Matthew White
Navy Joining Center
Edison Welding Institute
(614) 688-5241
matthew_white@ewi.org

Section 4

Surface Preparation & Coating Technologies (SP-3 Panel)

CHAPTER SUMMARY:

Surface preparation and coating activities in U.S. shipyards continue to be challenged by a variety of issues. Perhaps the greatest impact has been through constraints imposed by federal and state environmental regulations. The challenge of compliance has been and continues to be an ongoing exercise of transitions for most shipyards. Although typically arduous to the bottom line, these transitions have sometimes resulted in process improvements that provide a healthy return on capital expenditures, such as plural component spray equipment and powder coating lines. Other constraints include the inherent parameters of local climatic conditions and the impact of other trade activities on the surface preparation and coating processes.

Although surface preparation and coating of ships is a broad and highly technical field, it has yet to achieve the same level of attention as other shipyard activities relative to improving efficiency. The cost for repair and maintenance of existing coating systems has caused many ship owners to specify improved corrosion control systems that achieve longer life cycles. The result is an increased quality expectation by the customer which drives the industry to a higher level of sophistication in terms of coating materials and application processes. To remain competitive, shipyards must embrace the evolving surface preparation and coating technologies as they improve their other fabrication and repair processes.

The SOA report identifies process areas and builds strategies and technologies for surface preparation and coatings that have a positive impact on the overall shipbuilding process. Equally important to the continuous stimulation, development, and implementation of new technologies is the need to explore the efficiencies of current paint shop processes. Metrics of performance have also been identified as a baseline for measuring the efficiency of current preparation and coating processes. To assess the benefits of new technologies or compare U.S. shipyards to foreign competition, it is necessary to improve the benchmarking capabilities within shipyard paint shops.

The surface preparation and coating processes described in this report represent areas of opportunity for enhanced competitiveness and profitability. The report discusses nine discrete processes with emphasis on the interrelationships among themselves and other shipyard processes. Some of the process categories provide a response to regulatory parameters and customer demands, while others address new technologies in shipbuilding and the often overlooked inefficiencies of basic processes. In fulfilling its mission within the MARITECH ASE NSRP, the SP-3 Panel will prioritize and commit further resources to the exploration and definition of these process categories. The resulting efforts will be used to identify state-of-the-art best manufacturing practices and to recommend future investments in shipyard surface preparation and coating processes.

Sequencing and Integration

INTRODUCTION:

The sequencing and integration of surface preparation and coating processes are critical components of the pre-construction planning function and build strategy. Each stage of construction is carefully assessed and placed in balance with the product's coating specifications. Since shipbuilding is an orchestration of multiple trade disciplines, these processes must also be properly blended into the overall scheme to optimize preservation system performance and cost efficiency.

STATE OF THE INDUSTRY:

Most shipyards have dedicated planning departments that create and maintain detailed schedules of work. To produce an optimum work schedule or plan, careful consideration is given to each trade task and how it integrates with other trade tasks. Typical new construction planning objectives include maximizing surface preparations and coating applications early in the manufacturing process. The actual plan or build strategy, relative to maximum coating applications, must be balanced against the constraints associated with the specific coatings being applied (e.g., coatings maximum re-coat interval). Additional considerations that influence the overall integration and sequencing of coatings into the build strategy include:

- Cost per unit surface area at various points in the manufacturing process.
- Anticipation of hot work or other damages to coatings applied early in construction.

- Accessibility to surfaces requiring coating late in construction.
- Process impact on other trades.
- Facility limitations.
- Environmental compliance.

The ultimate goal for surface preparation and coating sequence and integration is to eliminate non-value added labor and rework occurrences.

STATE OF THE ART:

Planning efforts differ in approach and philosophy from one shipyard to the next. Regardless, shipbuilders continue to explore, develop, and utilize computer technologies to assist in the planning effort. Line item tasks or events are defined, stored, and eventually retrieved for integration into a construction plan. Sequencing of events is generally based on deckplate logic. The greatest attribute associated with computer aided planning is the timely ability to input, retrieve, and sort events relative to the applied logic.

STATE OF RELATED INDUSTRY:

Large commercial construction projects depend on effective sequencing and integration of events to achieve profitability. As in shipbuilding, limitations and constraints must be defined to effectively coordinate and schedule multiple trade events. Avoidance of rework, delays, and disruptions associated with subcontract work are common objectives that are addressed when developing a construction plan. Computer technology is also utilized in support of non-shipbuilding commercial construction.

ENABLING TECHNOLOGIES:

The evolution of computer technology continues to provide business solutions for all aspects of manufacturing. Versatile programming capabilities allow end users to achieve timely assessments of scheduling options relative to sequencing and integration of events. In the absence of deckplate experience, crucial historical data can be readily preserved for future planning efforts.

MANUFACTURING STRATEGIES:

Computer technology will not entirely replace the deckplate experience necessary to incorporate proper logic into a plan. However, technology does exist for developing models and programs that work in harmony with historical data to produce a build strategy influenced by practical shipbuilding logic. Of significant value to the shipbuilder is the ability to predict the costs associated with the integration of an event at any point in the manufacturing process. Process models, populated with historical performance data specific to a stage of manufacturing, can be drawn on to provide a cost analysis of an event at the precise point of schedule integration. Different scenarios can be explored to determine optimum sequencing and integration points based on economics rather than speculative experience.

Surface Preparation and Coating Process Control

INTRODUCTION:

Surface preparation and coating process control is a management activity that monitors performance to budget, relative to progress. Using this process, paint department managers can perform an analytical assessment of productivity on discrete work orders or labor charges.

STATE OF THE INDUSTRY:

The format of surface preparation and coating process control varies from shipyard to shipyard. Typically, the paint department is provided with a budget for a specific project based on historical performance to a comparable scope of work. Budgeted labor hour allocations also vary relative to allowances (e.g., discreet process functions; work order package). As work progresses to the scope of work defined, periodic reports account for labor hour expenditures. Progress is generally measured in terms of percentage of workscope completed, which is then compared to actual labor hour expenditures to gauge performance. Since assessment is commonly based on the human element, the measurement of progress is often subjective. This subjectivity, however, is minimized by incorporating an increased level of detailed process progression values into the budgeted scope of work. The ability of the paint department manager to electronically collect and assess data has also been dramatically improved. Computer aided process control is offering greater opportunity due to the increased availability throughout the supervisory ranks of manufacturing.

STATE OF THE ART:

Although most shipyards have developed a computer aided systems approach to process control, these approaches are as individualized as the shipyards. The formats and programs suited to managing surface

preparation and coating process data, however, are certainly capable of being developed and integrated with other shipyard systems. Paint department managers or supervisors could also electronically access time accounting data in a standard shipyard format. The stumbling block is trying to configure the data in order to measure performance and manage the process.

Surface preparation and coating activities in shipyards involve a large number of discreet processes worthy of analytical definition. Based on surveys of NSRP participating shipyards, a need exists to capture productivity values to a more discreet level. There is also a desire to develop a program capable of integrating actual labor hour expenditures so as to produce an accurate analysis of discreet process costs and rates. Such an capability would allow managers to compare real-time productivity to baseline process rates as a measure of performance, and assess the cause and effect of process changes in a timely manner. Beyond the inherent value as a daily management tool, strategic planning models could be developed to take advantage of process cost and rate data to estimate costs for proposed new work.

STATE OF RELATED INDUSTRY:

For this area, further evaluation and collaboration is underway.

ENABLING TECHNOLOGIES:

The SP-3 Panel sponsored four NSRP projects related to capturing and utilizing shipyard surface preparation and coating costs:

- Economics of Shipyard Painting Phase I: NSRP Report #0227
- Economics of Shipyard Painting Phase II: NSRP Report #0302
- Economics of Shipyard Painting Phase III: NSRP Report #0316
- Surface Preparation and Coating Bid Estimating Transfer Study: NSRP Report #0403

The initial project was based on the need to capture discreet surface preparation and coating costs by process, and to format a database program to create accurate and reliable bid estimates. During the execution of Phases I and II, it became apparent that a number of non-paint shop manufacturing activities caused variances in productivity. Phase III then focused on identifying and capturing those variances (e.g., lost time due to an inability to start a job assignment; rework due to incomplete or poor quality trade work). An ability to capture this information and assess performance to baseline costs/rates was deemed to be critical to the timely identification of production inefficiencies. Too often, the cost impact of these variances were overlooked because of their consolidation within standard cost collection line items. The final project in the series examined the degree to which technology could be transferred to other shipyards. With the exception of software differences, these transfers were successful.

MANUFACTURING STRATEGIES:

Timely availability of cost and progress information has driven shipyards to provide database accessibility to their first line supervisors of surface preparation and coating processes. To be efficient, this approach must be able to identify cost variances from a baseline early enough to prevent a negative impact to cost, as well as conduct timely analyses of process changes to take advantage of implementing improvements. The research conducted by the SP-3 Panel has established a foundation for shipbuilders to create programs for managing surface preparation and coating processes. Since the conclusion of this research, computer technology has advanced to the point where adapting and building on the findings of the SP-3 projects would have even greater value than originally expected.

Pre-Construction Priming

INTRODUCTION:

Pre-construction priming refers to the process by which ferrous steel plates and shapes, as received from the mill, are preserved prior to fabrication. The primary objective of this process is to reduce the cost of secondary surface preparations in the later stages of ship construction.

STATE OF THE INDUSTRY:

Pre-construction priming of raw steel stock is principally an automated process. Most new construction shipyards use dedicated facilities for removing mill scale and depositing coatings to protect the steel from corrosion during the fabrication process. The process incorporates a centrifugal abrasive blast cleaning system along with a configuration of automated spray guns for applying primer. Pre-heat and post-heat ovens accelerate primer dry times, resulting in timely material handling. Conveyor systems allow the raw steel stock to be transferred throughout the entire process. Pre-construction primer performance, in terms of corrosion protection longevity, is generally tailored to the duration of a shipyard's fabrication cycle through structural

completion of a block assembly. The block assembly is then prepared and coated using the primary coating systems specified by the invoked contract specifications.

The ability to retain the pre-construction primer to the furthest extent allowed by the specifications is desirable. Consequently, the integrity and condition of the primer at the scheduled time of primary coating system application is critical to the minimization of secondary surface preparation and resulting costs. In addition to the attributes of preservation and retention, the majority of U.S. and foreign shipyards apply primers with weld-through capabilities as well. Pre-construction primers that meet these requirements are available in various generic types. Regardless of the primer type but without disregarding the effects of surface profile after blasting, the most critical factor to success is controlling the consistency and quality of the primer's dry film thickness. Very little tolerance exists between the minimum requirements for preservation and the maximum coating thickness that will not impact weld quality and speed.

STATE OF THE ART:

In the last 10 to 15 years, significant advances have been made in the formulation of pre-construction primers due to the productivity and efficiency demands of shipbuilders. European and Far East shipbuilders were the first to challenge the coating manufacturers into developing primers capable of being retained throughout a ship with minimal secondary surface preparation prior to topcoating with the final paint system. In addition, these primers were required to meet the demands of high speed welding without compromising quality. The technology that emerged focused on vastly improved solvent-based inorganic zinc paints. Enhancements included improved corrosion protection at lower film thicknesses with less zinc; higher welding speeds; higher heat resistance; improved weathering; and greater versatility for retention in immersion service. Environmental compliance demands have also spawned water-based inorganic zinc paints and epoxy paints. Each type of primer varies in terms of performance relative to the desired attributes. Selection of pre-construction primer thus becomes a function of a shipyard's manufacturing strategy and regulatory compliance issues.

Regardless of primer capability, maximum value can only be realized if the product is used within its performance parameters. Surface preparation is typically accomplished with steel shot or grit. The abrasive mix is balanced in terms of type, hardness, and particle-size distribution to achieve a near-white metal finish with a minimal surface profile. The result is optimum coating performance at low dry film thicknesses. The centrifugal blast equipment is thus sized and configured to accomplish the required cleaning rates. Configuration and type of the spray system is critical to successful primer application. Designs vary relative to target geometries, transfer efficiencies, types of primer, production rates, and levels of automation. Steel plates allow for simple application system solutions, whereas structural shapes are more challenging due to variances in spray nozzle distance and angle of attack relative to the target surface geometry. All of the systems function within a balance of constraints dictated by line speed.

STATE OF RELATED INDUSTRY:

Pre-construction priming lines require significant capital to install and maintain. Consequently, fabricators of heavy steel products will typically procure the steel pre-primed. Most steel producers have access to priming lines whereby they can prepare and prime the steel to meet customer specifications. Such specifications can vary significantly in terms of performance expectations. A non-shipbuilding customer may place more emphasis on corrosion protection than on weldability, thus dictating the type of primer and level of application tolerance. Except for configuration differences, the basic processes of centrifugal blast cleaning and automated spray application are similar to those used in shipbuilding.

ENABLING TECHNOLOGIES:

De-scaling technology has not significantly changed in recent years. Centrifugal blast equipment paired with recyclable steel abrasives continues to be the optimum surface cleaning methodology. Primer application systems have been enhanced through computer integrated controls. Spray systems can be programmed to electronically acquire target surfaces; adjust to specific angles and heights; and, trigger on and off to produce greater application control. Existing pre-construction primer formulations offer the shipbuilder ample opportunity to reduce manufacturing costs if applied in accordance with the coating manufacturer's parameters.

MANUFACTURING STRATEGIES:

De-scaling (surface preparation) and primer application processes must be tuned to achieve

optimum primer longevity at the lowest dry film thickness. The centrifugal blast surface preparation system must be engineered to achieve a Steel Structures Painting Council (SSPC) SP-10 near-white finish with a minimal surface profile at the desired line speed. The primer application system must be capable of achieving complete coverage of both plate and shaped steel at a uniform dry film thickness. In terms of primer selection, the system must be suited to the shipyard's welding processes and performance expectations, as well as to the expectations of maximum retention with reduced secondary surface preparation.

Primary Surface Preparation

INTRODUCTION:

Primary surface preparation refers to the preparation and painting of incoming structural steel plates and shapes prior to fabrication. Mill scale and rust are removed using centrifugal blasting equipment and recyclable steel abrasives. The new steel is then coated with a weld-through pre-construction primer to protect the surface from corrosion and preserve the surface profile imparted during the cleaning process. Primary surface preparation methods are well suited for automation, and support the cost reduction strategies of the MARITECH Advanced Shipbuilding Enterprise program. For shipyards that cannot use the weld-through pre-construction primers, primary surface preparation refers to the initial blast cleaning of structures prior to coating.

STATE OF THE INDUSTRY:

The use of recyclable steel abrasives with automated blast cleaning production lines represents the state of the industry for removing mill scale and corrosion products prior to applying the pre-construction primer. Mill scale and rust are removed from standard structural shapes and steel plates in an efficient and economic manner. The use of recyclable steel abrasives allows the desired surface profile to be imparted to the steel, while producing a minimum of solid waste.

Following the blast cleaning process, a pre-construction primer is applied to the steel to protect the surface from corrosion until the steel is needed for new construction or repair. In recent years, pre-construction primers have been developed that do not require removal prior to cutting or welding of the steel. Known as weld-through primers, these primer coatings produce substantial cost savings by reducing the amount of manpower and material required to prepare the structural steel parts for assembly. Most commercial shipyards or contracting authorities allow the direct application of anti-corrosive paints and topcoats over these pre-construction primers, at least for dry spaces, which further enhances the economics of surface preparation and preservation. However, the recent trend toward 100% solids coatings may change this approach depending on the ability of the solids coatings to adhere well to the pre-construction primer.

STATE OF THE ART:

The abrasive must impact the steel with enough force to remove mill scale and rust, as well as impart a surface profile to the steel. The technology for this process is well developed and relatively inexpensive. To advance beyond this level, other factors must be considered such as improving the longevity of the paint system by reducing surface contaminants to an absolute minimum; the continued development, appropriate use, and controlled application of protective coatings; and the increased use of robotics in blasting technology to reduce the human element. One method of eliminating surface contaminants is by using ultra-high pressure (UHP) waterjet blasting with garnet injection. UHP has been shown to reduce chloride contamination to below detectable levels using ordinary municipal fresh water supplies.

The two primary factors that drive surface preparation technology are stricter environmental regulations and economic issues. Primary surface preparation is performed indoors, which permits the use of efficient controls for airborne emissions of fugitive blasting dust and volatile organic compounds (VOCs). Consequently, process improvements and technologies (e.g., reduce material, manpower, and waste disposal costs; improve operator health and safety while lowering worker protection costs) have the potential to increase shipyard competitiveness and advance the state of the art in shipbuilding.

STATE OF RELATED INDUSTRY:

Other industries, specializing in the construction of large, outdoor steel structures (e.g., bridges, water towers, tanks), use a primary surface preparation similar to that of the shipbuilding industry. Steel shapes and subassemblies are blast-cleaned, primed, and shipped to the construction site for assembly. In addition, shipbuilding and non-shipbuilding industries are both influenced by the same environmental and economic drivers.

The railcar industry is employing robotic blast machines for its primary surface preparation. These machines can use higher blast pressures than could

be used by humans, resulting in faster cleaning rates. The large aircraft manufacturing industry also shares characteristics of the shipbuilding industry, although its challenges are significantly different. Here, large aluminum panels are first cut and shaped to net form, then an adhesive primer is applied using automated application equipment. Film thickness and environmental conditions are closely controlled. Under these conditions, the aircraft industry recognizes that the best corrosion protection possible over the life of the aircraft is the original equipment manufacturer (OEM) primer to substrate bond. Additionally, the surface cleanliness and environmental conditions during the primer application of the secondary surface preparation operations will never match those of the OEM. The result is substantial ramifications with regard to cost and waste reductions during the secondary surface preparation processes.

ENABLING TECHNOLOGIES:

The development of weld-through primers has reduced manufacturing costs and ensured surface preservation. In addition, 100% solids coatings are having a positive impact on VOC emissions. A systems approach to the use of 100% solids coatings with weld-through construction primers is required to preserve these manufacturing benefits.

MANUFACTURING STRATEGIES:

The manufacturing strategy is to continue maximizing the use of primary preparation and pre-construction primers for plates and shapes. This approach will provide good corrosion prevention during the fabrication process and reduce downstream coating costs.

Secondary Surface Preparation

INTRODUCTION:

Secondary surface preparation refers to the re-preparation and re-painting of steel structures during ship fabrication or repair. For new construction, this process is required for welds and damaged areas after the structures have been fabricated and prior to the application of the final paint system. Abrasive blasting is usually used to remove old coatings and corrosion products as well as to impart a profile to the substrate. In cases where blasting is impractical, mechanical tools are used instead. Consequently, improvements in tooling and coating systems can reduce the costs and schedule impact from secondary surface preparation.

STATE OF THE INDUSTRY:

Secondary surface preparation, by blasting, is generally accomplished using recyclable steel shot, steel grit, mineral (garnet), or mineral slag abrasives. Small blast pots and abrasive hoppers are placed near the job site, and tarps or enclosures are used to contain blasting debris. Vacuum systems recycle the abrasive. Dust collectors and ventilation equipment are used to control the environment. Containment of fugitive dust in tanks and voids is not difficult, but regardless of where performed, the ability to provide sufficient ventilation and airflow to meet worker health and safety requirements adds an additional cost and productivity burden. Prevention of fugitive emissions during paint removal operations on superstructures can be accomplished by building plywood and lumber containment structures, or by using the superstructure itself as the support framework for polyethylene shrink-wrap containments.

Portable, centrifugal wheel, abrasive blasting machines with recyclable steel abrasives are used to remove thick non-skid deck coatings. Vertically-oriented, centrifugal wheel, blasting machines can also be used to remove coatings on hulls and boot tops. In some cases, the use of recyclable abrasives is not permitted on underwater hulls, so mineral slag abrasives (e.g., coal slag) are used to remove the paint system and prepare the underwater hull for paint application.

Mechanical secondary surface preparation is accomplished with needleguns, disk sanders, roto-peen tools, and hand wire brushes. Some mechanical tools have vacuum attachments to prevent worker exposure to heavy metals (e.g., lead, chromate) during the removal of old coatings.

STATE OF THE ART:

Closed-cycle ultra-high pressure waterjet (UHPWJ) blasting is quickly becoming the method of choice for removing hull coatings. The water is near-instantaneously collected at the blast head, filtered, and reused, thereby eliminating the generation of collateral waste and leaving a surface free of chlorides and other contaminants. Garnet can be injected to impart a profile to the surface, if necessary. The recent trend has been to use magnetic crawlers to manipulate the UHPWJ systems about the hull. Similar developments have occurred in the use of

closed-cycle abrasive blast machines with magnetic crawlers for exterior hull blasting. Operators run these machines at a distance via a joystick. Although expensive to purchase, the closed-cycle abrasive blast machines can be operated without shutting down adjacent hull fabrication work, which reduces downtime and improves schedules.

A major improvement in state of the art involves the way paint removal is envisioned. The current trend is moving toward a tool-box approach for secondary surface preparation. For complete removal of paint on hulls, UHPWJ systems are being employed. Portable, centrifugal blast machines throwing recyclable steel grit are used for removing deck coatings. For touching up paint damage, engineered media such as sponge-jet urethane foam abrasive has been investigated. To reactivate the surface of pre-construction primer prior to applying the final coating system, CO_2 pellet blast has been explored and shows great promise.

STATE OF RELATED INDUSTRY:

Other industries, specializing in the repair of large, outdoor steel structures, use recyclable steel abrasives with total containment as their primary method for secondary surface preparation. Tanks can be cleaned using UHPWJ systems, but the complexity of the shapes precludes this approach for repairing the coatings on bridges and water towers. To remove lead paint, chemical stripper systems such as Peel-Away® are used. While it is more expensive than open abrasive blasting, chemical stripping is approximately one-quarter to one-half the cost of building large, negative-pressure, containment structures and reduces worker exposure to toxic materials.

ENABLING TECHNOLOGIES:

To determine the best match from all of the available surface preparation technologies, organizations must determine a more accurate cost estimate of a particular surface preparation method, including equipment, materials, labor, and waste disposal. Currently in shipyards, the true cost of surface preparation is difficult to estimate. Sponge-Jet® urethane foam abrasive, CO_2 pellet blast, and other technologies have been investigated to ascertain their potential use. Convincing management to employ a new technology requires solids, cost-saving estimates, particularly when large outlays for capital equipment are necessary.

MANUFACTURING STRATEGIES:

Many new techniques can reduce the costs of secondary surface preparation. Among these are better scheduling of fabrication operations; use of robotic blasting machines; use of high pressure waterjet and CO_2 blasting techniques; and the development of more surface-tolerant coating systems.

Liquid Coating

INTRODUCTION:

Liquid coating is the primary shipyard method for protecting structures, components, and piping from corrosion. These coatings also provide resistance to fouling; increase fire resistance; identify safety requirements; and support habitability schemes. Application of liquid coatings to ships is still very labor intensive and costly. However, state-of-the-art methods are available to reduce these costs and shorten preservation schedules.

STATE OF THE INDUSTRY:

Liquid coatings are applied by brushes, rollers, and spray equipment. The choice of spray equipment is determined by the type and viscosity of the coating to be applied; the type and size of area to be coated; and the desired surface finish.

Conventional equipment pressurizes paint with air to push the liquid/air mixture through a hose and atomize it in the spray gun at approximately 30 to 40 psi. Airless equipment uses an air-driven pump to push only the liquid through the hose using a spray gun tip pressure of around 3,000 to 4,500 psi. The higher pressure permits the application of higher viscosity coatings and larger volumes of paint per unit time. Air-assisted airless equipment is similar except that it operates at a spray gun tip pressure of less than 950 psi. The lower pressure allows better control of the flow stream and applied thickness. High volume-low pressure (HVLP) equipment uses low pressures for applying interior enamels and creates virtually no overspray. The spray gun tip pressure is typically five to ten psi. Plural component equipment uses separate fluid pumps to force resin and catalyzed components through a static mixer and then to the spray gun. This equipment can apply coatings with very high viscosities and short pot lives using spray gun pressures from 4,000 to 7,000 psi.

Two component epoxy paints are the predominant anti-corrosive coatings for shipyards, with lesser amounts of inorganic zinc, alkyd, latex, and acrylic coatings used. High solids epoxy paints (less than

20% solvent) are being used for tank interiors and free-flood spaces. Their higher viscosity allows better protection in fewer coats, which reduces labor costs. Inorganic zinc, pre-construction primers are applied automatically to plates and shapes prior to fabrication. These coatings can be welded through, and their zinc content prevents corrosion until final painting (interior dry spaces only) or removal for applying epoxy paints in wetted or immersed areas.

STATE OF THE ART:

Automated, pre-construction, priming lines are state of the art for plates and shapes. Plural component equipment is state of the art for applying high viscosity, multi-component paints to hulls, free-flood spaces, and tank interiors. Plural component equipment only mixes what will be sprayed and reduces waste of multi-component paints. This method also reduces the amount of solvent needed to clean equipment because only the static mixer, downstream hose, and spray gun are exposed to the catalyzed paint. A drawback to plural component equipment is the high initial cost. HVLP equipment is state of the art for applying low viscosity, interior, finish enamels by greatly reducing the masking of adjacent areas which, in turn, reduces labor costs.

STATE OF RELATED INDUSTRY:

The railcar industry has used plural component spray equipment for years to apply high viscosity coatings. The automotive industry relies on electrocoating and robotic spray application methods. Electrocoating is not presently used by the shipbuilding industry and robotic application of coatings is limited to pre-construction priming lines and automated powder coating applications. These related industries are also ahead of the shipyards in their methods employed to identify and track liquid coating of parts. Barcodes and electronic buttons attached to parts can be scanned to ensure that the correct liquid paint is applied. Infrared sensors have been developed for paint spray guns by the automobile repair industry to ensure the painter maintains a constant, uniform distance from the substrate, thereby improving the quality of the finish.

ENABLING TECHNOLOGIES:

Automatic mixing and dispensing equipment for paints can decrease labor costs and reduce waste. Robotic application of coatings is suitable for repetitious applications for standard shapes or structures. Electronic technologies can support better tracking of parts through the preservation process, and ensure that the correct coatings are applied. Computerization of warehouse inventories and paint issue points in shipyards can support more efficient use of coatings and reduce costly waste.

MANUFACTURING STRATEGIES:

Better computerization of liquid coating inventories and just-in-time deliveries can reduce costs. Improved training of production planners in surface preparation and painting requirements can better integrate paint processes into the rest of the ship fabrication work. Continued use of pre-construction primers as well as the development of better topcoats to eliminate secondary surface preparation would improve liquid coating processes and reduce costs.

Powder Coating

INTRODUCTION:

Powder coating is a process in which partially catalyzed resins and curing agents in a powder form are applied to metal parts, and then baked in an oven. The heat from the oven causes the powder to liquefy, flow, gel, and harden — thereby making a uniform continuous film that is tough and durable. Powder coatings do not emit solvents to the environment, nor do they create hazardous waste. The coatings are typically applied by electrostatic spray equipment or with fluidized beds. The parts being coated must be able to withstand the surface preparation method (e.g., typically an abrasive blast) and the powder curing temperature (e.g., 300°F to 400°F for 20 minutes). The increased use of powder coatings in shipyards can greatly reduce labor costs for preservation as well as provide more durable coating systems.

STATE OF THE INDUSTRY:

Over the last seven years, several major U.S. shipyards have installed powder coating facilities. These facilities perform either batch work on a few parts at one time or use automated equipment that can coat thousands of parts per week. The majority of parts weigh between 10 and 150 pounds, although parts of up to 6,000 pounds have been coated in batch operations. Pipe and electrical hangers, fixtures, small foundations for machinery, hatches, louvers, deck plates, gauge boards, furniture, and

miscellaneous structures are routinely powder coated. Gas-fired convection ovens are most frequently used for curing. Automated facilities can be operated by one or two workers, which greatly reduces labor costs for the preservation process. Some shipyards contract their powder coating work to outside job shops, especially for hangers and furniture. Powder coating of large parts for ships has rarely been done, but has the potential to reduce coating costs.

STATE OF THE ART:

Infrared ovens can raise the surface temperature of a part to the powder curing temperature without heating the entire unit, which is conducive to quicker curing times and increased through-put. Ultraviolet (UV) light curing methods are used in non-marine industries to quickly cure thin films. Some commercial powder coating companies have coated steel parts of up to 30 tons (e.g., bridge girders). Special electrostatic spray guns are available that can overcome the Faraday cage effect that prevents powder from being applied to recesses and tight spaces. Large fluidized bed units can apply uniform powder thicknesses to complex shapes. Laser inspection devices are being developed to measure the thickness of applied powder, prior to baking, to ensure first-time quality.

STATE OF RELATED INDUSTRY:

Hundreds of commercial powder coating companies can be found throughout the U.S., and there are also many appliance and metal furniture manufacturers, automobile makers, and electronic industry suppliers that apply powder coatings. Infrared ovens; UV curing methods; and robotic application of powder are often used by companies that coat large numbers of similarly shaped parts. Most shop setups can make quick color changes and apply a wide variety of powder formulations. Non-marine industries typically apply thinner films of powder coating compared to what is needed for good performance in marine environments.

ENABLING TECHNOLOGIES:

Infrared ovens; UV curing methods; and robotic application of powder have the potential to extend the powder coating process to more shipbuilding parts than currently being addressed. Infrared ovens raise the surface temperature of a part to the powder curing temperature without heating the entire unit, which reduces process times. UV curing methods may be suitable for interior dry spaces where thin powder films are acceptable. Improved handling methods would allow larger parts to be coated.

MANUFACTURING STRATEGIES:

Maximizing the use of powder coatings in shipbuilding requires a good understanding of the manufacturing requirements for the parts. Parts must be sent to the powder coating shop at the proper time in the construction cycle to benefit from the quick curing times, and to obtain the best coverage while minimizing downstream paint repairs. Parts must also be able to withstand the oven temperatures needed to cure the powder.

Environmental Technologies

INTRODUCTION:

Environmental technologies are used to comply with federal, state, and local environmental regulations for air quality, water quality, and hazardous waste management. These technologies also include methods to control temperature, relative humidity, dew point, solvent vapor concentrations, and other similar conditions during surface preparation and coating operations. Environmental compliance and control technologies can directly impact shipyard profits. Consequently, a variety of technical methods are available for meeting these challenges.

STATE OF THE INDUSTRY:

Shipyard preservation operations are subject to federal, state, and local environmental regulations for air quality, water quality, and hazardous waste management. In 1998, new federal regulations were invoked for controlling solvent emissions from shipyard paints. Most shipyards limit these emissions by controlling the solvent content in the purchased paint and by eliminating thinning, rather than employing control equipment to filter, capture, and destroy solvent vapors. Some local air quality permits mandate specific spray equipment to improve paint transfer efficiency and reduce emissions. Shipyards use dust collection systems, tents, and/or tarps to control paint overspray and to meet federal regulations for emission of nuisance dust. Many shipyards use solvent stills to reduce their solvent wastestreams and to recycle solvent for cleaning spray equipment. Blowers help keep paint solvent vapor concentrations in confined spaces below explosive limits, while refrigerant, desiccant, and compressed air dryers help shipyards comply with paint manufacturer's instructions for temperature, relative humidity, and dew point. A key environmental issue for shipyards is preventing the discharge of drydock liquid wastes

that contain heavy metals generated by paint removal and application operations. Frequent sampling of drydock wastewater and its associated control are increasingly expensive burdens to shipyards.

STATE OF THE ART:

Technology for maintaining air quality includes dry filtration systems, impaction devices (e.g., water curtains), electrostatic precipitators, and organic vapor control devices (e.g., carbon adsorption). Risk can be a factor if the use of this equipment becomes a condition of one's air quality permit. Should the equipment break or malfunction, the paint shop operations must shut down, thereby impacting ship fabrication schedules. Biodegradable materials in wastewater can be handled with aerobic and anaerobic treatment processes. Non-biodegradable materials are controlled with advanced oxidation, carbon adsorption, or thermal destruction methods. Wastewater-suspended, solids treatment processes involve gravity separation and clarification; filtration-plate and frame pressure; filtration with mono- and multi-media; pre-coat filtration; and, most recently, membrane or ceramic ultrafiltration. Solid waste can be reduced with high pressure waterjet blasting, instead of abrasive blasting, by using proportional mixers and pumps for multi-component coatings, by using large volume storage containers (e.g., 400-gallon totes), and by using improved application guns that reduce paint overspray. Disposal of sludge via thickening processes may reduce wastewater solids. Filter presses, decanters, and industrials centrifuges are available to concentrate sludges in a tertiary treatment process.

STATE OF RELATED INDUSTRY:

National emission standards for hazardous air pollutants have and are being formulated for other major industries that use coatings (e.g., aircraft, furniture, appliance, electronic products). The solvent emission limits for these coatings are different; hence, the coating solutions are not necessarily transferable to the shipbuilding industry. The size and shape of related industry's products are more conducive to technological controls for capturing solvent vapors, whereby most of the surface areas of ships are painted in outdoor environments or large buildings. In some industries, the use of powder coatings has significantly reduced solvent emissions and hazardous waste. The technologies used for environmental compliance by related industries must be studied on a case-by-case basis to determine their feasibility for shipyards.

ENABLING TECHNOLOGIES:

The computerization of inventories and tracking of paint usage can help ensure compliance to solvent emission regulations. Improvements in waterborne coating chemistry may ease the environmental burden associated with solvent-borne paints. Waterjet blasting can easily remove old coatings and clean surfaces while producing low volumes of waste; however, issues regarding overcoating of flash rust must be resolved. High-powered vacuum systems can be used to control and capture spent abrasive and liquid wastes.

MANUFACTURING STRATEGIES:

By minimizing the number and types of coatings to be applied, the overall environmental impact can be reduced. Low solvent content coatings, waterborne coatings, and powder coatings that usually achieve equivalent performance levels as high solvent content coatings have been developed for marine applications. Performing surface preparation and painting at the proper time in the fabrication sequence can reduce paint re-work and its corresponding environmental impact. Plural component mixing and spray equipment can reduce hazardous wastes from multi-component paints.

Quality Management

INTRODUCTION:

Quality management is the process by which the quality of purchased coatings, surface preparations, coating applications, curing, and final acceptance is achieved. This process also involves the training of paint shop and inspection personnel on quality attributes. Shipyard preservation costs can be reduced by developing clear and focused quality management programs, and by increasing the level of computerization of the quality process.

STATE OF THE INDUSTRY:

U.S. shipyards have adopted various quality management programs whose individual history can usually be traced to a specific quality problem at that shipyard. In addition, all shipyards provide some form of on-the -job or formal training, relative to quality attributes, to their blasters and painters. Paint inspectors attend either in-houses courses or those offered by professional technical societies such as the SSPC or the National Association of Corrosion Engineers (NACE). Shipyard painting procedures typically contain hold-points for inspection of surface

preparation; compliance to surface preparation visual standards; measurement of film thicknesses; evaluation of environmental conditions; ventilation methods; and compliance with paint manufacturer's instructions. Inspection tools include replica tape for measuring blast profiles; electronic or mechanical devices for measuring paint thicknesses and environmental conditions; chemical tests to determine the presence of detrimental chlorides; and video cameras to record conditions to track coating performance. A key issue affecting quality is trying to determine the ideal time in the fabrication process to perform preservation. If preservation is performed too soon, additional costs for re-work of paint damage caused by other shipyard operations may occur. If preformed too late, additional costs may be necessary to ensure that the preservation process does not impact adjacently installed components or machinery.

STATE OF THE ART:

Improved computerization of paint thickness gauges allows thousands of measurements to be automatically recorded and downloaded to a personal computer for evaluation, process control, and tracking of coating performance. Digital cameras allow quick and easy recording of paint conditions, and enable electronic transfer of data for quick disposition of repair instructions. Electronic devices are available for on-site measurement of residual chlorides after blasting. The U.S. Navy uses robots to inspect the paint conditions on underwater hulls, thereby avoiding costly drydocking. Ultrasonic gauges are being developed which can detect subsurface coating flaws on composite materials. This technology may be able to detect corrosion activity occurring at the juncture of the substrate and coating, even when no visual changes in coating appearance are present. Pictorial standards have been developed for abrasive waterjetting.

STATE OF RELATED INDUSTRY:

Total quality management and ISO-9000 certification programs have raised the quality level of coatings for the automotive industry, appliance manufacturers, and makers of other consumer goods. The quality required in these industries for finish and appearance is generally much higher than those of the shipbuilding industry. Other industries such as bridge and refinery painting contractors use SSPC- or NACE-certified, third-party inspectors to ensure the quality of coatings. Non-marine industries employ a greater amount of specialized instrumentation to evaluate coatings for attributes such as gloss and waviness.

ENABLING TECHNOLOGIES:

Electronic measuring devices enable coating quality data to be evaluated quickly and consistently. Laboratory analysis equipment can verify that good quality coatings are received and can evaluate production problems. The adaptation of statistical process control techniques to paint shop operations would provide a better understanding of cost drivers and areas needing improvement. Better planning and scheduling programs would also allow preservation to be performed at the optimum time in the ship fabrication process, thereby reducing re-work costs.

MANUFACTURING STRATEGIES:

Increased computerization of quality procedures and attributes can significantly improve quality and reduce costs for shipyard painting practices. The ability to transmit electronic images of good quality and unacceptable paint conditions to the job site can help resolve quality issues in a more timely fashion. Electronic transmission of inspection reports and data will provide a faster method for determining quality trends and areas needing improvement. Dissemination of paint requirements and procedures via remote terminals, rather than hard copy procedures, offers faster responses to questions by shipyard trades. Selecting the optimum time during fabrication to perform preservation can significantly reduce re-work costs.

POINTS OF CONTACT:

For further information on SP-3 Panel items in this report, please contact:

Mr. Mark Panosky
General Dynamics, Electric Boat Corporation
(860) 433-8337
mpanosky@ebmail.gdeb.com

Mr. Scott DeVinney
General Dynamics, Bath Iron Works
(207) 442-3143
scott.devinney@biw.com

Mr. Charles Tricou
Applied Research Laboratory
The Pennsylvania State University
(814) 863-4459
cst101@psu.edu

Appendix A

Table of Acronyms

Acronym	Definition
APS	Atmospheric Plasma Spraying
ASE	Advanced Shipbuilding Enterprise
ATICTS	Automatic Tooling Inventory Control Tracking System
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CFM	Continuous Flow Manufacturing
CNC	Computer Numerical Control
DFMA	Design for Manufacturing and Assembly
DNC	Direct Numerical Control
EAS	Electric Arc Spraying
EB-NV	Electron Beam Non-Vacuum
EBW	Electron Beam Welding
EGW	Electrogas Welding
ESW	Electroslag Welding
FCAW	Flux Cored Arc Welding
FSW	Friction Stir Welding
GMAW	Gas Metal Arc Welding
GTAW	Gas Tungsten Arc Welding
HSLA	High Strength Low Alloy
HVLP	High Volume-Low Pressure
HVOF	High Velocity Oxy-fuel
HY	High Yield
JIT	Just-In-Time
LW	Laser Welding
NACE	National Association of Corrosion Engineers
NC	Numerical Control
NDE	Non-Destructive Evaluation
NDT	Non-Destructive Testing
NSRP	National Shipbuilding Research Program
OEM	Original Equipment Manufacturer
PAW	Plasma Arc Welding
RW	Resistance Welding

Acronym	Definition
SAW	Submerged Arc Welding
SMAW	Shielded Metal Arc Welding
SOA	State of the Art
SSPC	Steel Structures Painting Council
SW	Stud Welding
UHP	Ultra-High Pressure
UHPWJ	Ultra-High Pressure Waterjet
UV	Ultraviolet
VOC	Volatile Organic Compound
VPPA	Variable Polarity Plasma Arc

Appendix B

Contributors

Joseph C. Baumer
Newport News Shipbuilding
(757) 688-0405
baumer_jc@nns.com

Larry L. Blanchfield
Newport News Shipbuilding
(757) 688-8312
blanchfield_wl@nns.com

Hank L. Bowers
Newport News Shipbuilding
(757) 380-7263
bowers_hl@nns.com

Howard Bunch (retired)
University of Michigan Transportation
Research Institute
hbunch@umich.edu

Tommy Cauthen
Ingalls Shipbuilding
(228) 935-3815
cauthentl@ingalls.com

Scott DeVinney
Bath Iron Works
(207) 442-3143
scott.devinney@biw.com

J. L. 'Bull' Durham
Newport News Shipbuilding
(757) 380-4785
durham_jl@nns.com

Clifford Dutrumble
Electric Boat Corporation
(860) 433-7133
cdutrumble@ebmail.gdeb.com

Suren Dwivedi
University of Louisiana
(318) 482-5361
snd7483@usl.edu

Ed Hansen
Bath Iron Works
(207) 442-4927
ed_hansen.biw@ebmail.gdeb.com

Richard Holdren
Edison Welding Institute
(614) 688-5139
dick_holdren@ewi.org

Doug Ketron
Edison Welding Institute
(614) 688-5150
doug_ketron@ewi.org

Lee Kvidahl
Ingalls Shipbuilding
(228) 935-3564
kvidahllg@ingalls.com

Suzane Lavoie
Electric Boat Corporation
(860) 433-3968
slavoie@ebmail.gdeb.com

Michael Ludwig
Bath Iron Works
(207) 442-4025
mludwig@biw.com

Warren Mayott
Electric Boat Corporation
(860) 433-4214
wmayott@ebmail.ebgd.com

Jerry M. McVeigh
Newport News Shipbuilding
(757) 688-7956
mcveigh_gm@nns.com

Rick Nelson
Electric Boat Corporation
(860) 433-2000
rnelson@ebmail.gdeb.com

Mark Panosky
Electric Boat Corporation
(860) 433-8337
mpanosky@ebmail.gdeb.com

Charles Ribardo
Edison Welding Institute
(614) 688-5066
charlie_ribardo@ewi.org

Allan G. Roy
Newport News Shipbuilding
(757) 380-7117
roy_ag@nns.com

James Sawhill
Newport News Shipbuilding
(757) 380-7421
sawhill_jm@nns.com

David D. Sawyer
Newport News Shipbuilding
(757) 380-4013
sawyer_dd@nns.com

Charles Tricou
Applied Research Laboratory
The Pennsylvania State University
(814) 863-4459
cst101@psu.edu

John Talkington
Edison Welding Institute
(614) 688-5183
john_talkington@ewi.org

Joseph Bart Sickles
Concurrent Technologies Corporation
(814) 269-6444
sickles@ctc.com

Mike Sullivan
National Steel and Shipbuilding Company
(619) 544-8581
msulliva@nassco.com

Warren W. Vick
Newport News Shipbuilding
(757) 380-7147
vick_ww@nns.com

Matthew White
Navy Joining Center
Edison Welding Institute
(614) 688-5241
matthew_white@ewi.org

Dave G. Williams
Newport News Shipbuilding
(757) 380-4972
williams_dg@nns.com

Appendix C

Navy Manufacturing Technology Centers of Excellence

The Navy Manufacturing Sciences and Technology Program established the following Centers of Excellence (COEs) to provide focal points for the development and technology transfer of new manufacturing processes and equipment in a cooperative environment with industry, academia, and Navy centers and laboratories. These COEs are consortium-structured for industry, academia, and government involvement in developing and implementing technologies. Each COE has a designated point of contact listed below with the individual COE information.

Best Manufacturing Practices Center of Excellence

The Best Manufacturing Practices Center of Excellence (BMPCOE) provides a national resource to identify and promote exemplary manufacturing and business practices and to disseminate this information to the U.S. Industrial Base. The BMPCOE was established by the Navy's BMP program, Department of Commerce's National Institute of Standards and Technology, and the University of Maryland at College Park, Maryland. The BMPCOE improves the use of existing technology, promotes the introduction of improved technologies, and provides non-competitive means to address common problems, and has become a significant factor in countering foreign competition.

Point of Contact:
Mr. Ernie Renner
Best Manufacturing Practices Center of Excellence
4321 Hartwick Road
Suite 400
College Park, MD 20740
(301) 403-8100
FAX: (301) 403-8180
ernie@bmpcoe.org

Center of Excellence for Composites Manufacturing Technology

The Center of Excellence for Composites Manufacturing Technology (CECMT) provides a national resource for the development and dissemination of composites manufacturing technology to defense contractors and subcontractors. The CECMT is managed by the Great Lakes Composites Consortium and represents a collaborative effort among industry, academia, and government to develop, evaluate, demonstrate, and test composites manufacturing technologies. The technical work is problem-driven to reflect current and future Navy needs in the composites industrial community.

Point of Contact:
Mr. James Ray
Center of Excellence for Composites Manufacturing Technology
c/o GLCC, Inc.
103 Trade Zone Drive
Suite 26C
West Columbia, SC 29170
(803) 822-3708
FAX: (803) 822-3710
jrglcc@glcc.org

Electronics Manufacturing Productivity Facility

The Electronics Manufacturing Productivity Facility (EMPF) identifies, develops, and transfers innovative electronics manufacturing processes to domestic firms in support of the manufacture of affordable military systems. The EMPF operates as a consortium comprised of industry, university, and government participants, led by the American Competitiveness Institute under a CRADA with the Navy.

Point of Contact:
Mr. Alan Criswell
Electronics Manufacturing Productivity Facility
One International Plaza
Suite 600
Philadelphia, PA 19113
(610) 362-1200
FAX: (610) 362-1290
criswell@aci-corp.org

National Center for Excellence in Metalworking Technology

The National Center for Excellence in Metalworking Technology (NCEMT) provides a national center for the development, dissemination, and implemen-tation of advanced technologies for metalworking products and processes. The NCEMT, operated by Concurrent Technologies Corporation, helps the Navy and defense contractors improve manufacturing productivity and

part reliability through development, deployment, training, and education for advanced metalworking technologies.

Point of Contact:
Mr. Richard Henry
National Center for Excellence in Metalworking Technology
c/o Concurrent Technologies Corporation
100 CTC Drive
Johnstown, PA 15904-3374
(814) 269-2532
FAX: (814) 269-2501
henry@ctc.com

Navy Joining Center

The Navy Joining Center (NJC) is operated by the Edison Welding Institute and provides a national resource for the development of materials joining expertise and the deployment of emerging manufacturing technologies to Navy contractors, subcontractors, and other activities. The NJC works with the Navy to determine and evaluate joining technology requirements and conduct technology development and deployment projects to address these issues.

Point of Contact:
Mr. David P. Edmonds
Navy Joining Center
1250 Arthur E. Adams Drive
Columbus, OH 43221-3585
(614) 688-5096
FAX: (614) 688-5001
dave_edmonds@ewi.org

Energetics Manufacturing Technology Center

The Energetics Manufacturing Technology Center (EMTC) addresses unique manufacturing processes and problems of the energetics industrial base to ensure the availability of affordable, quality, and safe energetics. The focus of the EMTC is on process technology with a goal of reducing manufacturing costs while improving product quality and reliability. The EMTC also maintains a goal of development and implementation of environmentally benign energetics manufacturing processes.

Point of Contact:
Mr. John Brough
Energetics Manufacturing Technology Center
Indian Head Division
Naval Surface Warfare Center
101 Strauss Avenue
Building D326, Room 227
Indian Head, MD 20640-5035
(301) 744-4417
DSN: 354-4417
FAX: (301) 744-4187
mt@command.ih.navy.mil

Institute for Manufacturing and Sustainment Technologies

The Institute for Manufacturing and Sustainment Technologies (iMAST), was formerly known as Manufacturing Science and Advanced Materials Processing Institute. Located at the Pennsylvania State University's Applied Research Labortory, the primary objective of iMAST is to address challenges relative to Navy and Marine Corps weapon system platforms in the areas of mechnical drive transmission techologies, materials science technologies, high energy processing technologies, and repair technology.

Point of Contact:
Mr. Henry Watson
Institute for Manufacturing and Sustainment Technologies
ARL Penn State
P.O. Box 30
State College, PA 16804-0030
(814) 865-6345
FAX: (814) 863-1183
hew2@psu.edu

National Network for Electro-Optics Manufacturing Technology

The National Netowork for Electro-Optics Manufacturing Technology (NNEOMT), a low overhead virtual organization, is a national consortium of electro-optics industrial companies, universities, and government research centers that share their electro-optics expertise and capabilities through project teams focused on Navy requirements. NNEOMT is managed by the Ben Franklin Technology Center of Western Pennsylvania.

Point of Contact:
Dr. Raymond V. Wick
National Network for Electro-Optics Manufacturing Technology
One Parks Bend
Box 24, Suite 206
Vandergrift, PA 15690
(724) 845-1138
FAX: (724) 845-2448
wick@nneomt.org

Gulf Coast Region Maritime Technology Center

The Gulf Coast Region Maritime Technology Center (GCRMTC) is located at the University of New Orleans and focuses primarily on product developments in support of the U.S. shipbuilding industry. A sister site at Lamar University in Orange, Texas focuses on process improvements.

Point of Contact:
Dr. John Crisp, P.E.
Gulf Coast Region Maritime Technology Center
University of New Orleans
College of Engineering
Room EN-212
New Orleans, LA 70148
(504) 280-5586
FAX: (504) 280-3898
jncme@uno.edu

Manufacturing Technology Transfer Center

The focus of the Manufacturing Technology Transfer Center (MTTC) is to implement and integrate defense and commercial technologies and develop a technical assistance network to support the Dual Use Applications Program. MTTC is operated by Innovative Productivity, Inc., in partnership with industry, government, and academia.

Point of Contact:
Mr. Raymond Zavada
Manufacturing Technology Transfer Center
119 Rochester Drive
Louisville, KY 40214-2684
(502) 452-1131
FAX: (502) 451-9665
rzavada@mttc.org

INTERNET DOCUMENT INFORMATION FORM

A . Report Title: The Shipyard State of the Art Report

B. DATE Report Downloaded From the Internet: 12/12/01

C. Report's Point of Contact: (Name, Organization, Address, Office Symbol, & Ph #): Best Manufacturing Practices
Center of Excellence
College Park, MD

D. Currently Applicable Classification Level: Unclassified

E. Distribution Statement A: Approved for Public Release

F. The foregoing information was compiled and provided by:
DTIC-OCA, Initials: __VM__ **Preparation Date 12/12/01**

The foregoing information should exactly correspond to the Title, Report Number, and the Date on the accompanying report document. If there are mismatches, or other questions, contact the above OCA Representative for resolution.